MICROCHIP

LED Light for you

Intelligent LED drivers

Workshop UK 2015

14. April 2014

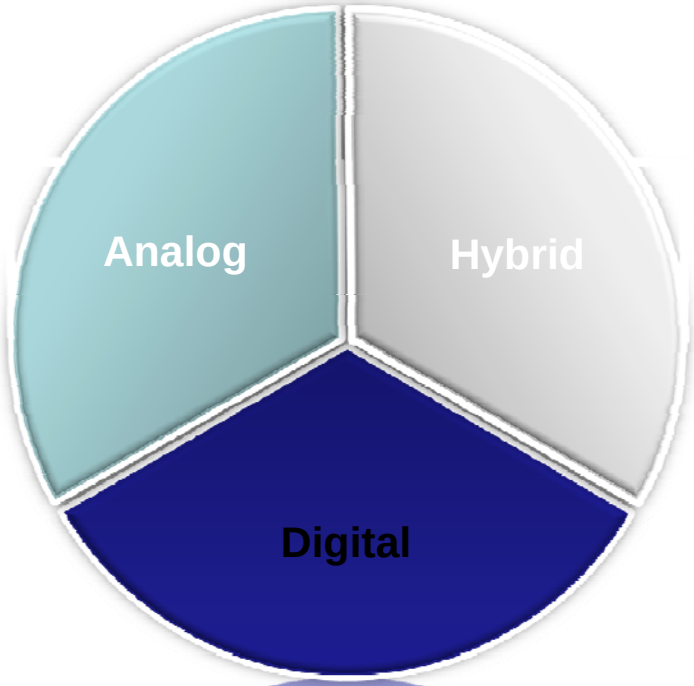
16. April 2014

Class Agenda

- **Basics**
  - LED Lighting
  - Power Conversion
  - LED Dimming
- **Hybrid Control with MCP1911x**
- **Hybrid Control with Core Independent Peripherals**
- **Digital Control**
  - Automotive Headlamp Example
- **Communication**

Different Aproaches Different Challenges

Standard and Enhanced Analog Controllers
Integrated solutions for dedicated topologies, power levels and applications



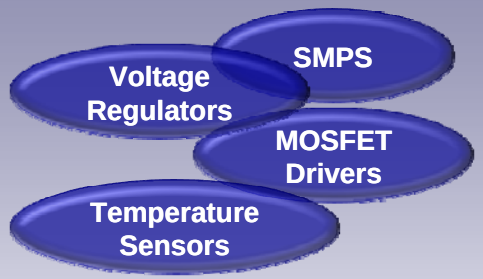
Programmable Digitally Enhanced Power Analog
Integrated solutions for various topologies, power levels and applications

Fully Digitally Controlled Systems
High-end control solutions for various topologies, power levels and applications providing highest flexibility

Scalable Product Portfolio

Analog

Up to 40V Analog Products
Discrete Power Conversion
Complementary PIC MCU attach



Wireless

Wi-Fi® 802.11 modules, ZigBee® RF4CE, MiWi™ 802.15.4 modules
Infrared/IrDA®

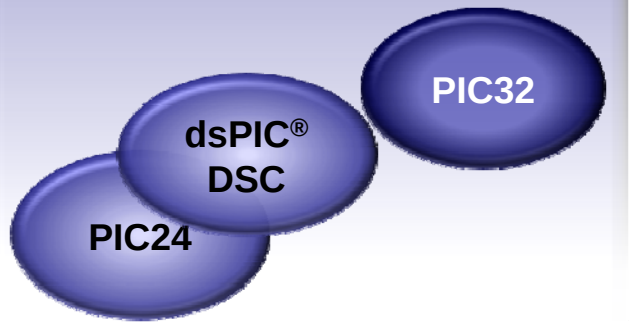
8-bit PIC® Microcontrollers

Luminaire Ballast & LED Drivers
Wall & Remote Controls
Intelligent Control Capabilities
Communication & Networking
<100W Optimized Power Conversion
Lowest Cost
Smallest Form Factors

PIC18
PIC16
PIC12
PIC10

16- & 32-bit PIC® Microcontrollers

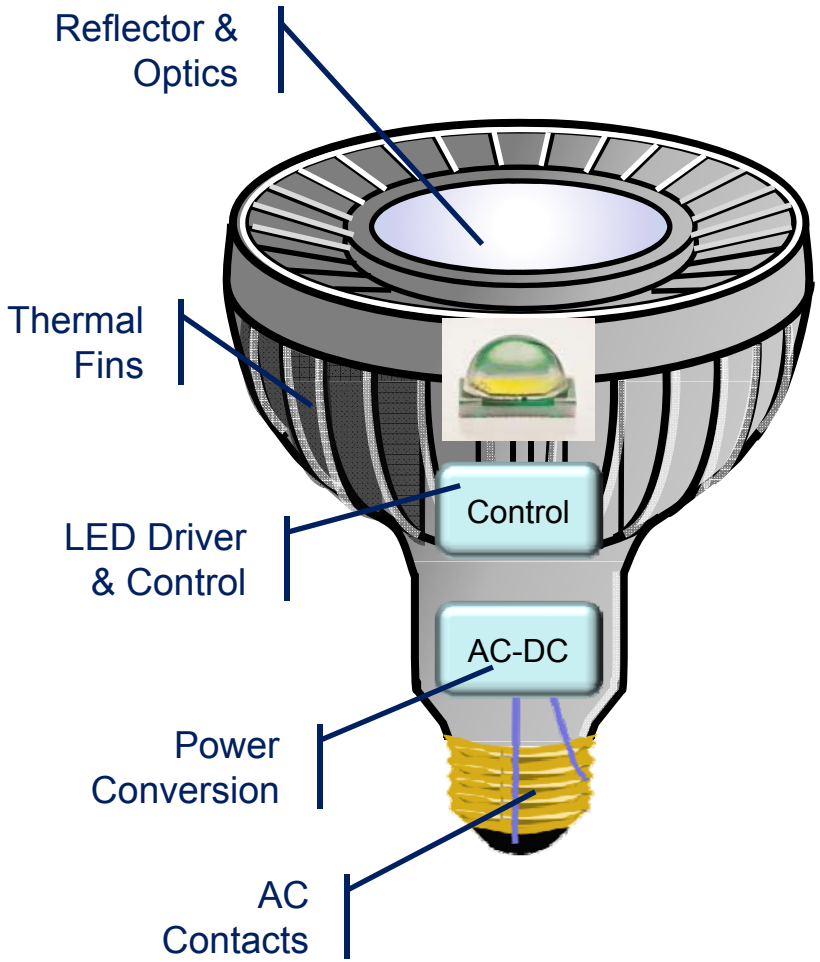
Advanced Controllers & Luminaires
Advanced Communication & Networking
• RF Gateways & Translators
• Power Line Carrier (PLC)
Advanced Intelligent Control Capabilities
>100W Advanced Power Conversion
Increased Performance
Increased Lighting Channels



Complementary Analog & Wireless RF Attach

Performance & Functionality

LED Lighting



Advantages

Best Overall Efficiency

- ~25-50% less energy than fluorescent
- >100 lumens/watt (efficacy)

Longest Life: >50,000 hours

No “warm-up”

Minimal Radiated Heat

Good in indoor and outdoor applications

Opportunity to provide additional intelligence

Disadvantages

Requires electronic drive to maintain constant voltage/current across LED

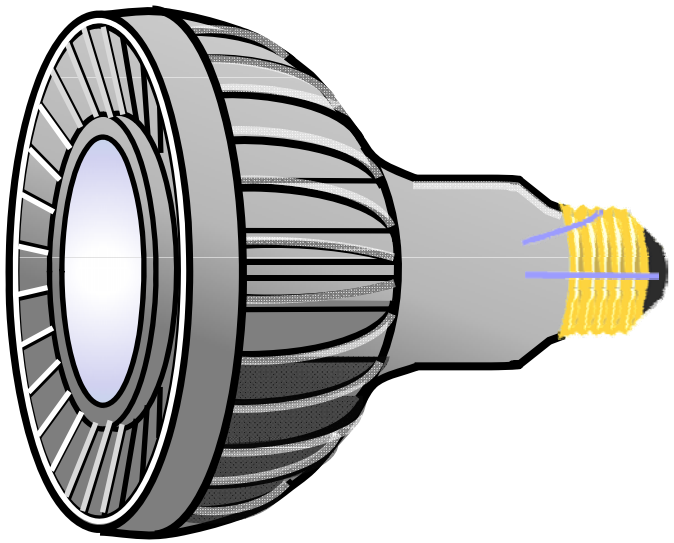
Requires thermal solution to remove conducted heat

LED Lighting
Microchip Value Add

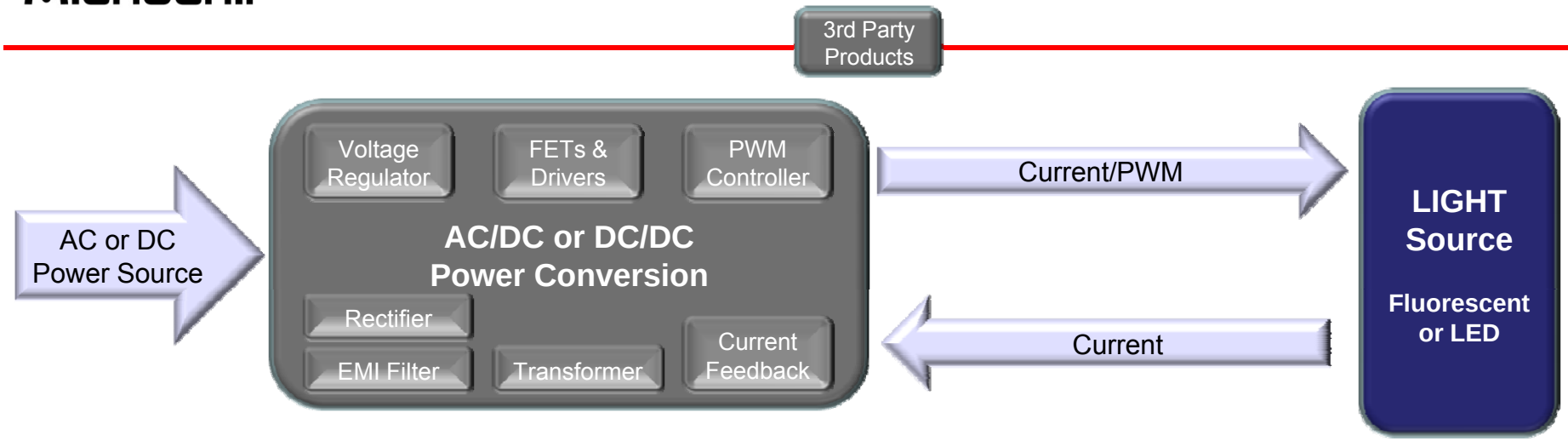
HBLED requires a constant control source or *"Driver"*

- A specific current/voltage is required to control light output
- Requires AC/DC or DC/DC Power Conversion
  - Various topologies available based on safety and design requirements

- **Efficient Power Conversion**
- **Power Factor Correction (AC Only)**
- **Constant current/voltage control**
- **High resolution dimming/current control of HBLED**
- **Advanced Control Capabilities**
  - Communications
  - Thermal Management
  - Dimming Control
  - Light Color Compensation
  - Light "Quality" → NO FLICKER
  - Fault Detection
  - Customization



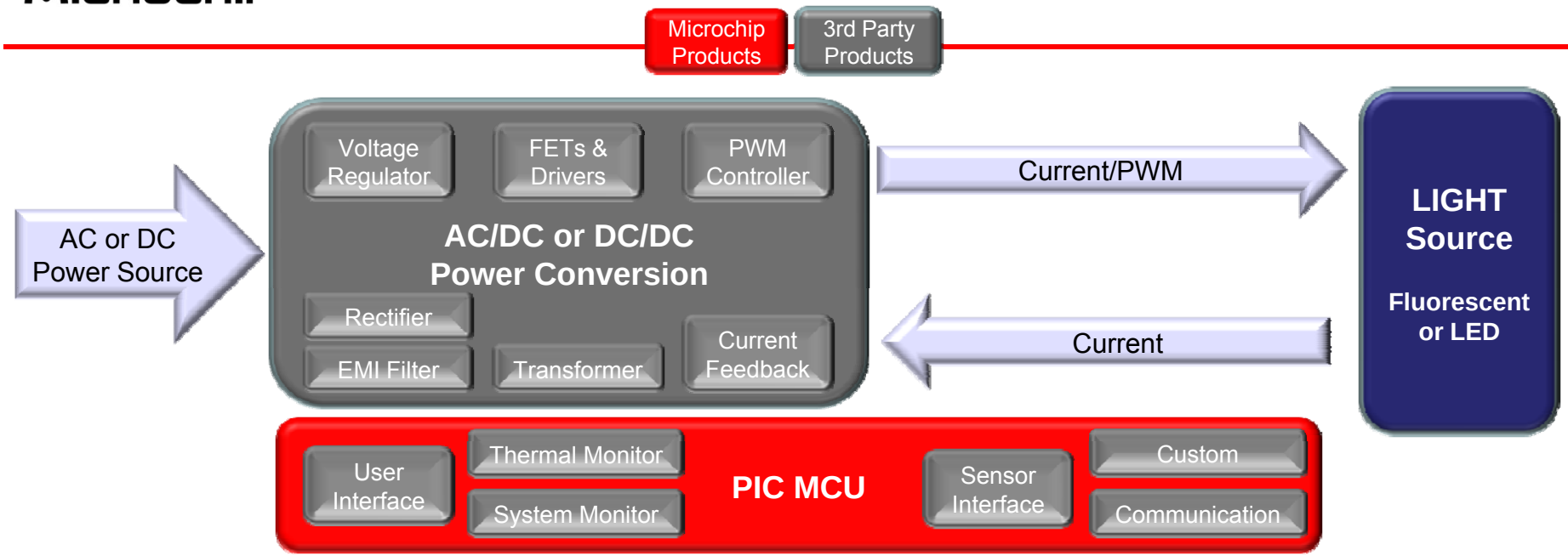
Basic Power Conversion



Commonly utilizes analog & fixed function devices (ASIC)

- Cheap, highly integrated power conversion blocks
- Fixed Function – Not customizable
- Component change required for any modifications
- Lacks “Intelligence”
  - Communications, Fail Safe Monitoring, Environmental Sensing, Etc.

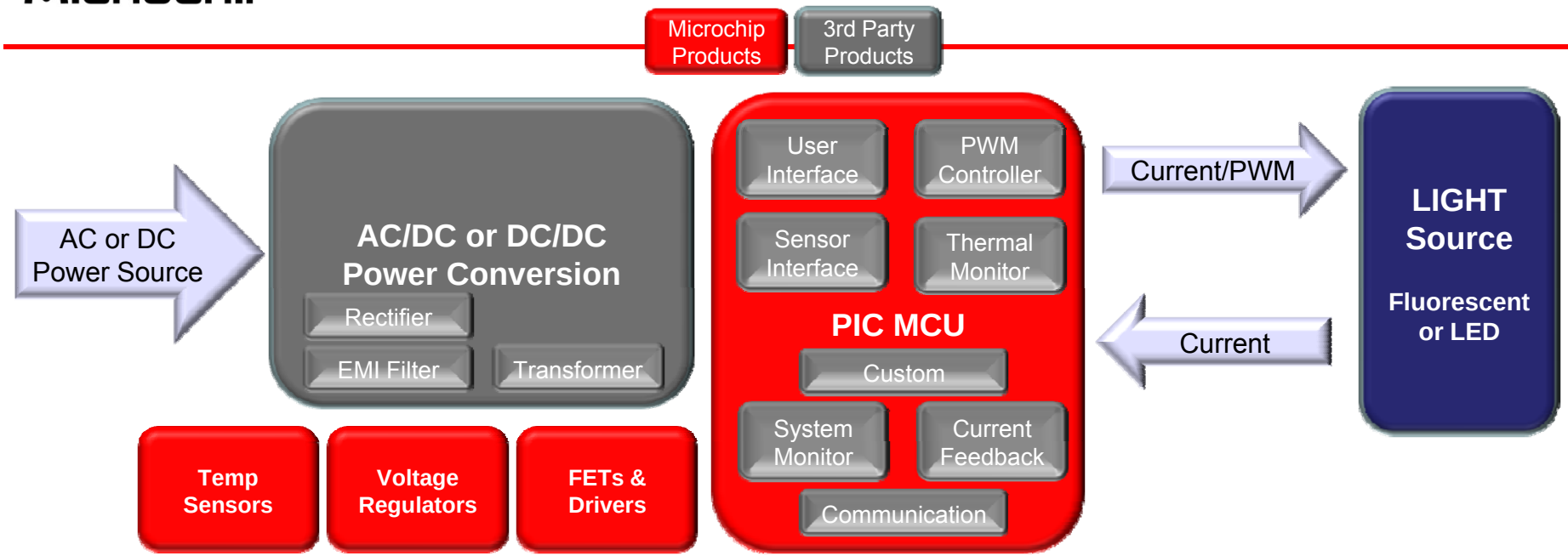
Hybrid Power Conversion



PIC® MCU attach to basic power supply

- Cost effective, simplified design-in
- Customizable features, simplified modifications via firmware
- Intelligent Control
  - Communications, Fail Safe Monitoring, Environmental Sensing, User Interface, Thermal Management, Fan Control, System Monitoring, Dimming, custom, etc.

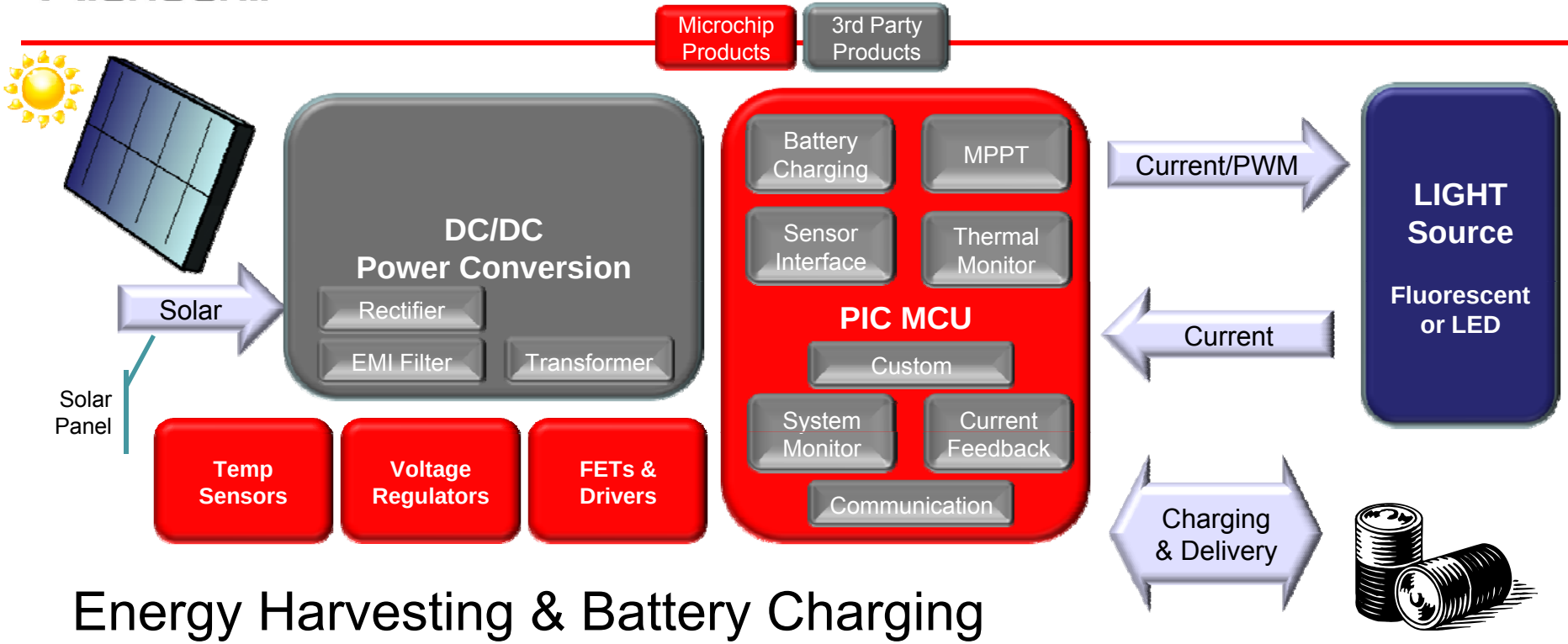
Advanced Power Conversion



Switch Mode Power Supply (SMPS with PIC® MCU & Analog)

- Increased MCU integration, increased efficiencies, flexible topologies
- Fully customizable, simplified modifications via firmware
- Closed loop control with high performance PWM variations
- Intelligent Control
  - Communications, Fail Safe Monitoring, Environmental Sensing, User Interface, Thermal Management, Fan Control, System Monitoring, Dimming, custom, etc.

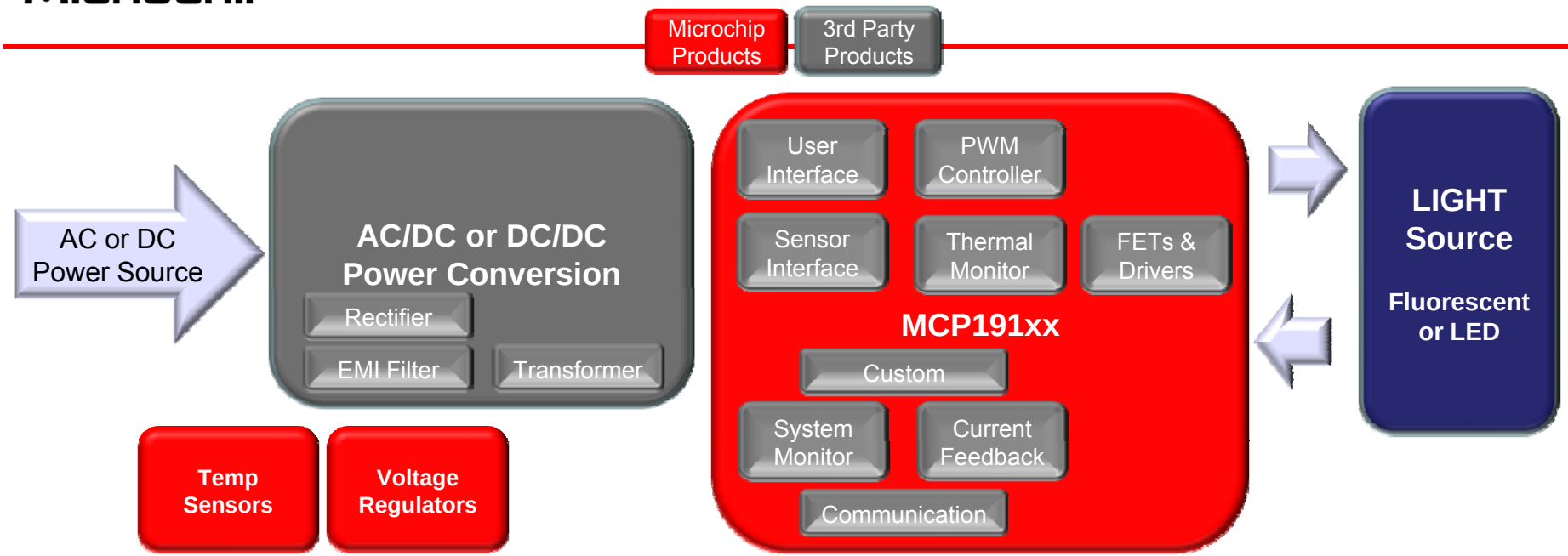
Energy Harvesting



Energy Harvesting & Battery Charging

- PIC® MCU controlled power conversion & battery storage
- Peak power tracking control, charging, & power delivery
  - Solar → Battery, Battery → Light Source
- Customizable MPPT & battery charging algorithms
- Support for various power supply topologies

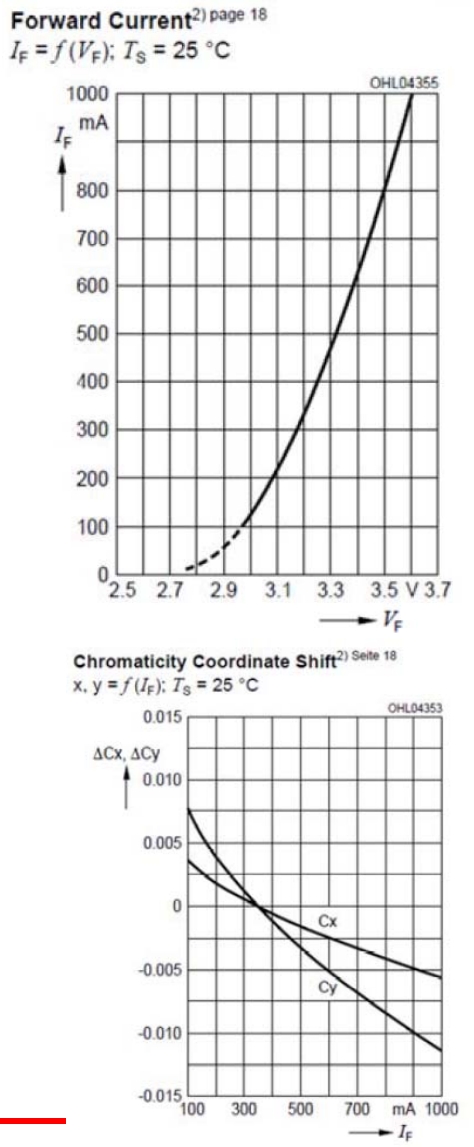
Advanced Integration

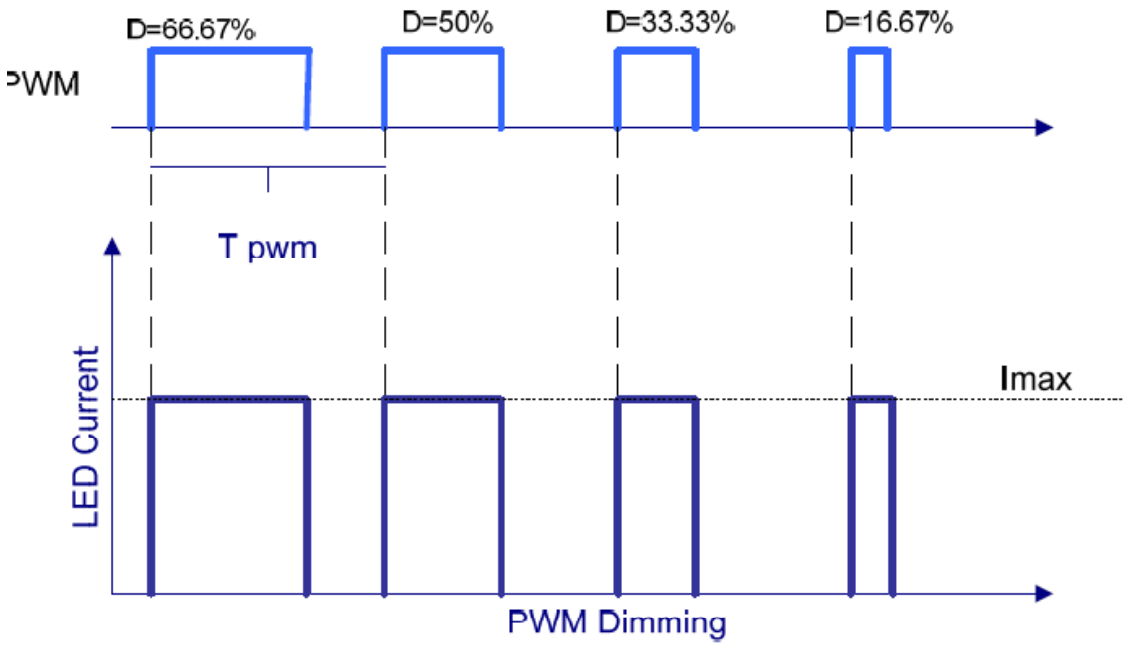


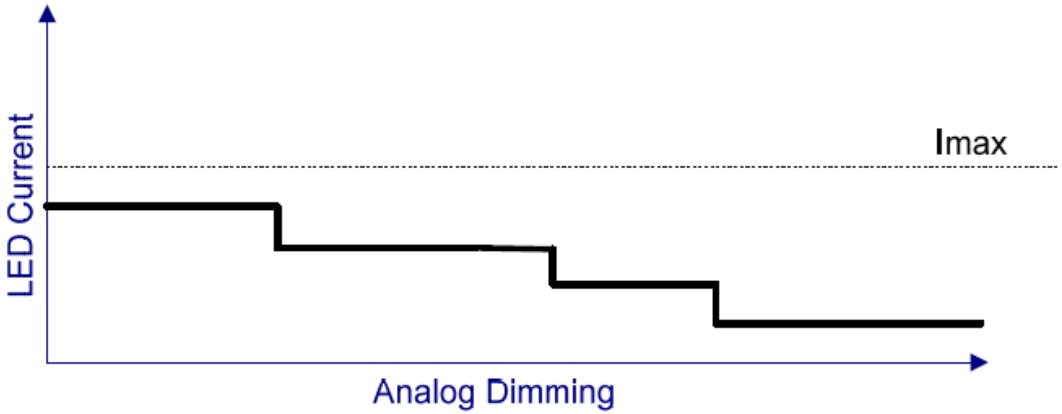
Switch Mode Power Supply (FET & Driver Integration)

- Increased MCU & analog integration, flexible topologies
- Fully customizable, simplified modifications via firmware
- Reduced complexity, component count, and footprint
- Intelligent Control
  - Communications, Fail Safe Monitoring, Environmental Sensing, User Interface, Thermal Management, Fan Control, System Monitoring, Dimming, custom, etc.

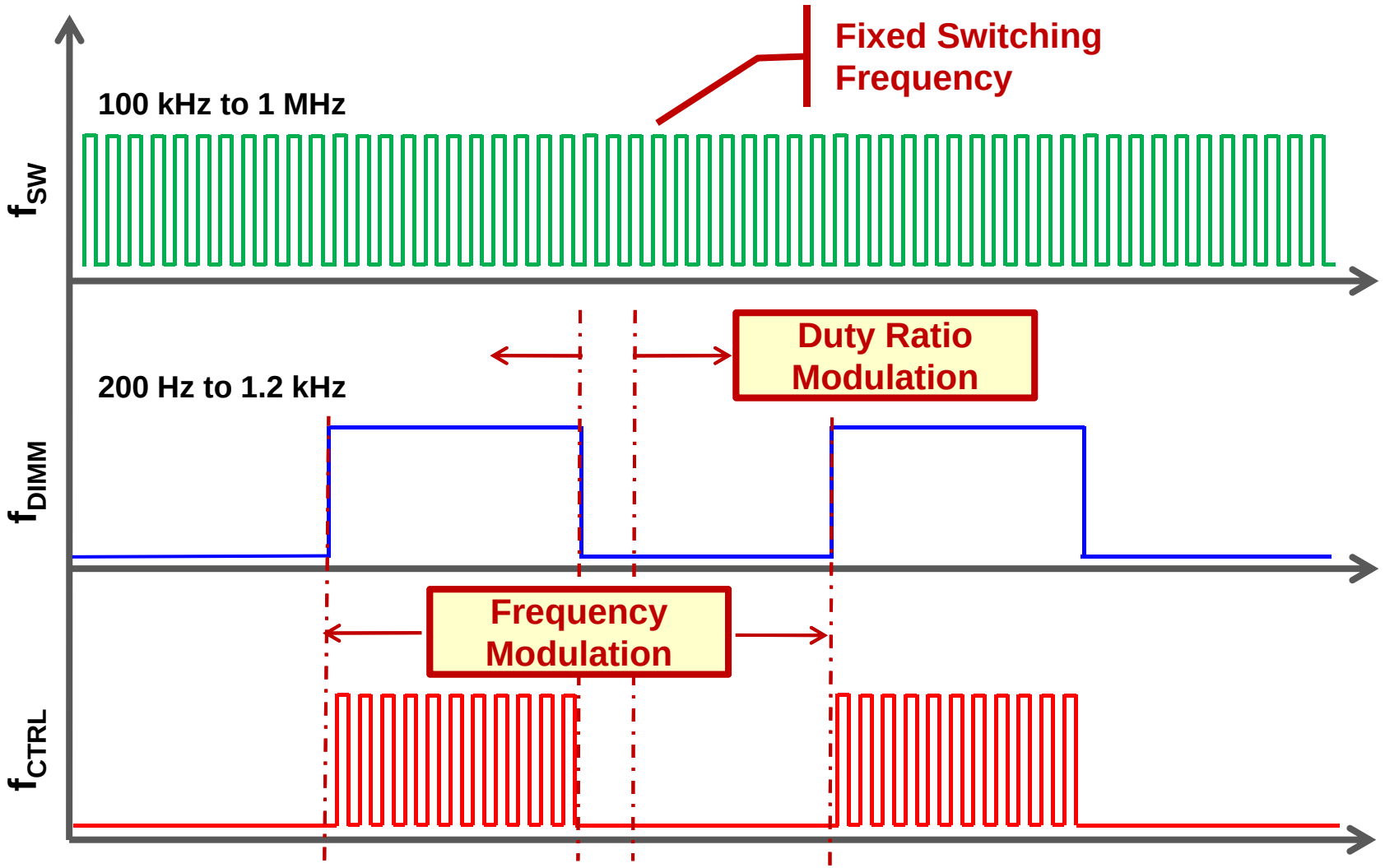
LED Dimming


Forward Current2) page 18
$I_F = f(V_F)$; T_S = 25 °C
OHL04355
1000
mA
I_F
800
700
600
500
400
300
200
100
0
2.5 2.7 2.9 3.1 3.3 3.5 V 3.7
V_F
Chromaticity Coordinate Shift2) Seite 18
x, y = $f(I_F)$; T_S = 25 °C
OHL04353
0.015
ΔCx, ΔCy
0.010
0.005
0
-0.005
-0.010
-0.015
Cx
Cy
100 300 500 700 mA 1000
I_F

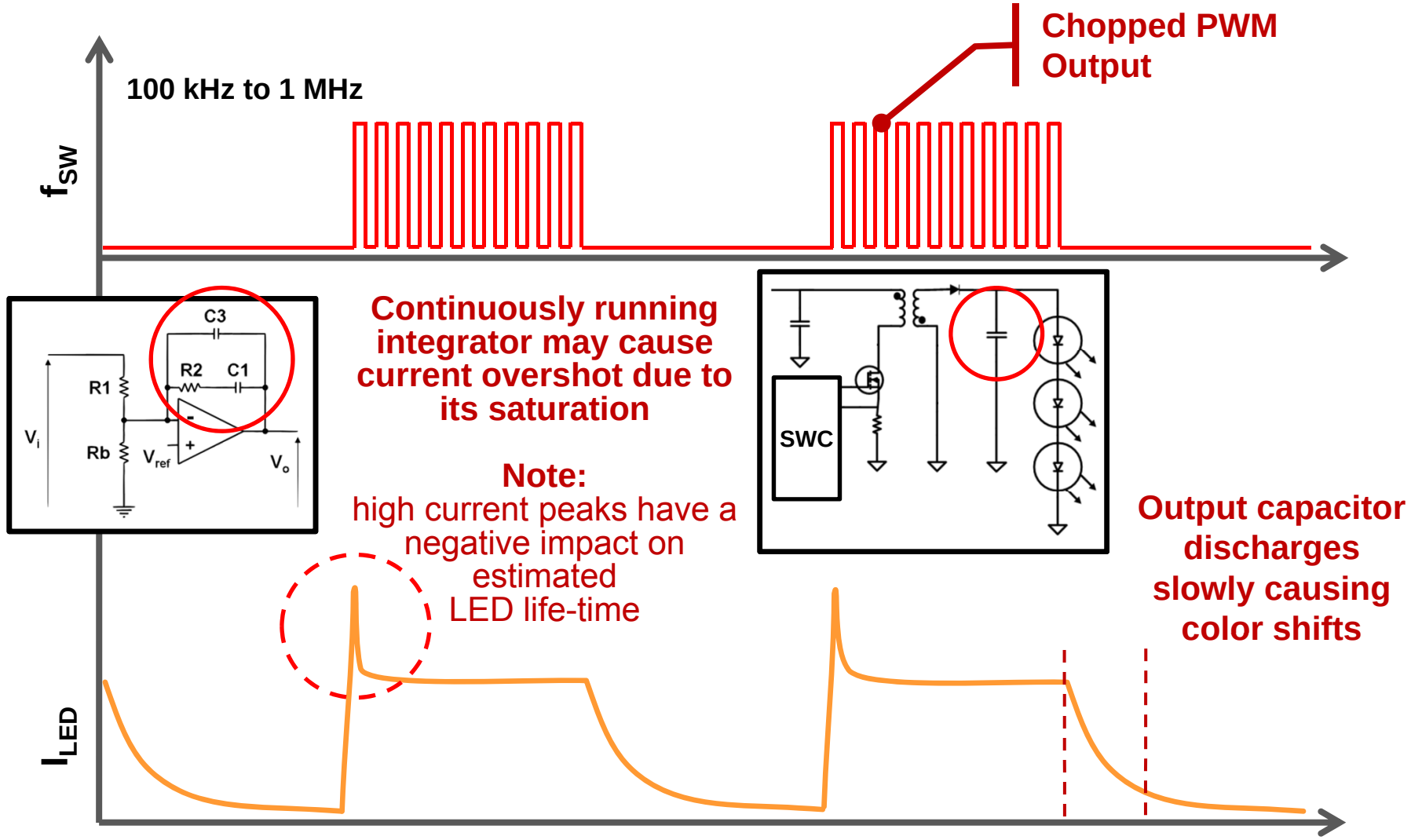

PWM
D=66.67%
D=50%
D=33.33%
D=16.67%
T pwm
LED Current
Imax
PWM Dimming


LED Current
Imax
Analog Dimming

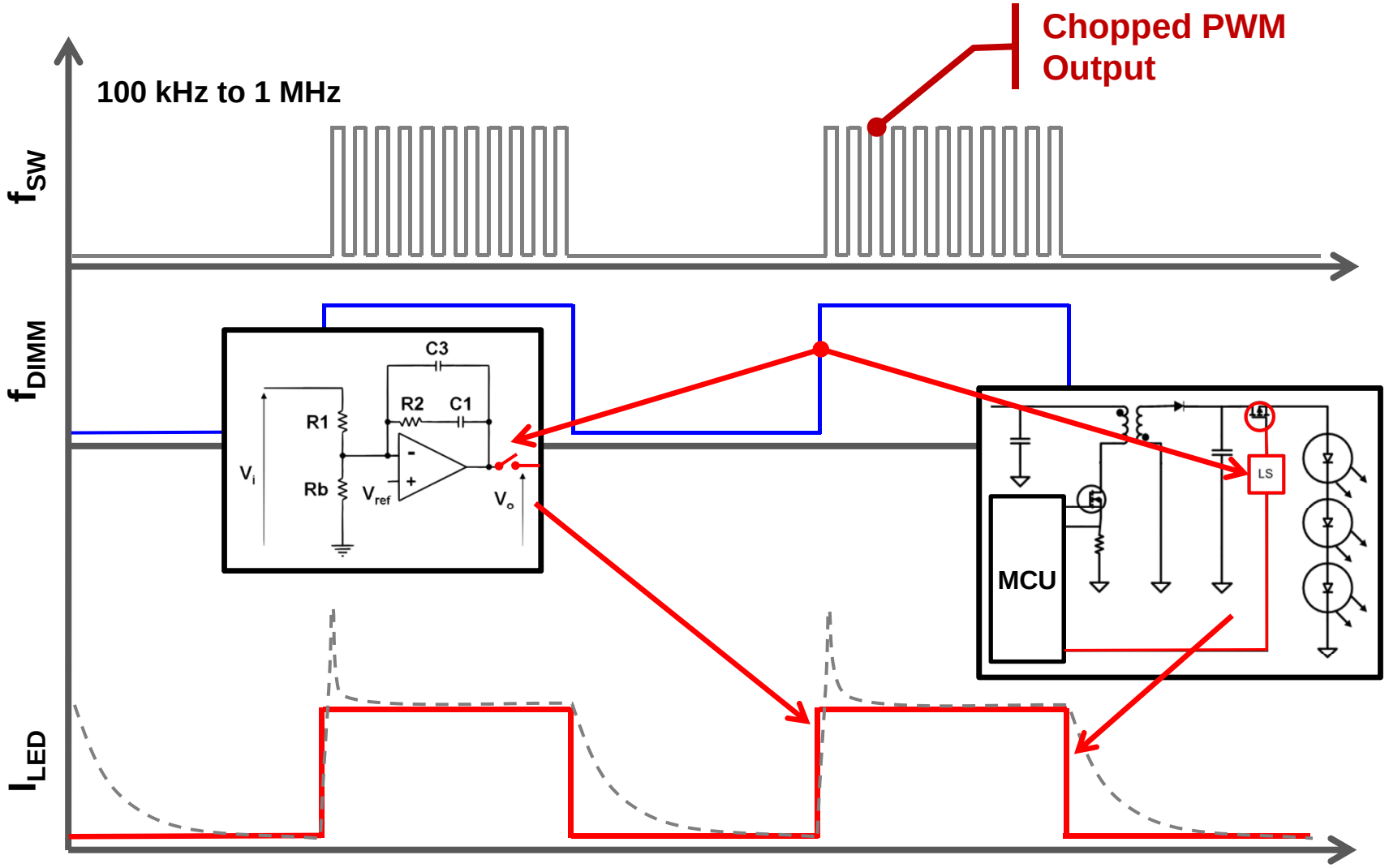
Enhanced Dimming
- Switching Frequency Generation -



Enhanced Dimming
- Common Dimming Technique -



Enhanced Dimming
- Dimming Enhancements -



Function Enablement

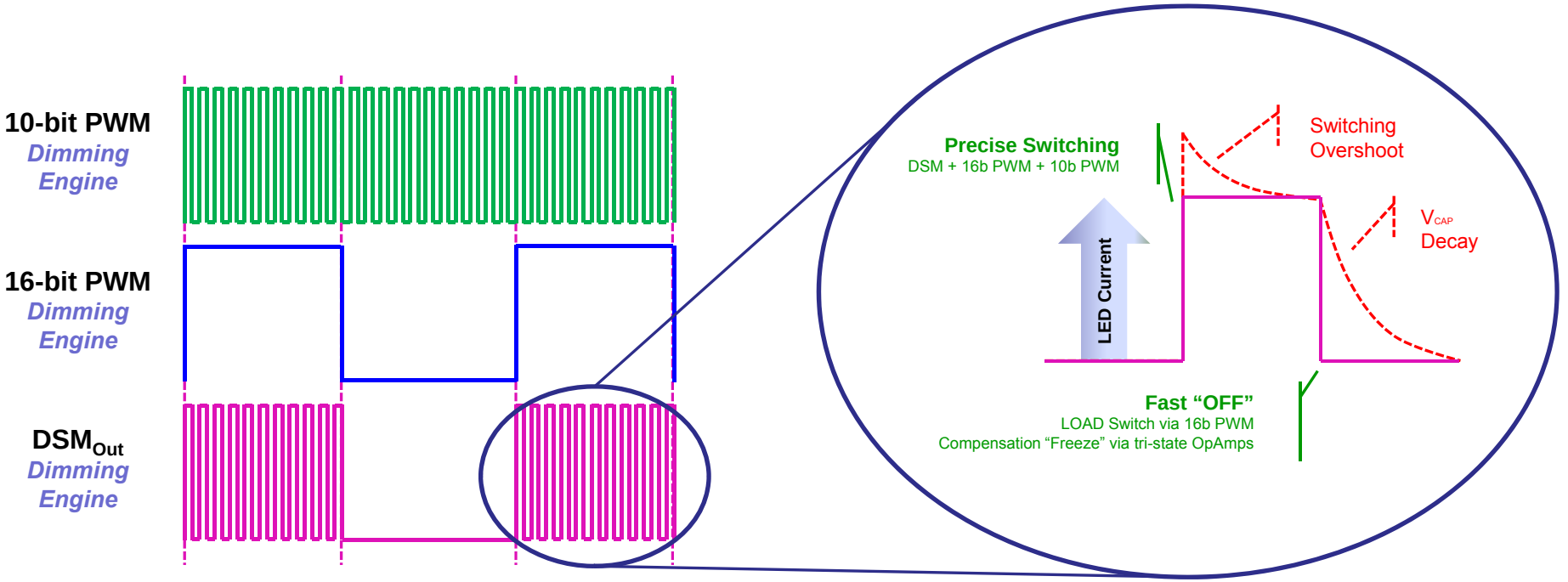
LED Dimming Engine - Benefits

LED Dimming Engine

Interconnection of 10-bit/16-bit PWM, DSM, & OpAmp

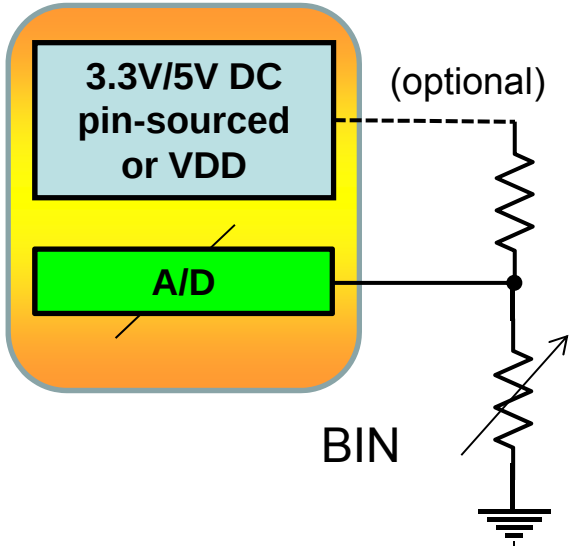
- Synchronized input / output switching
- Smooth signal switching
- Prevents partial signal glitching
- Stabilized output power
- Lower code overhead

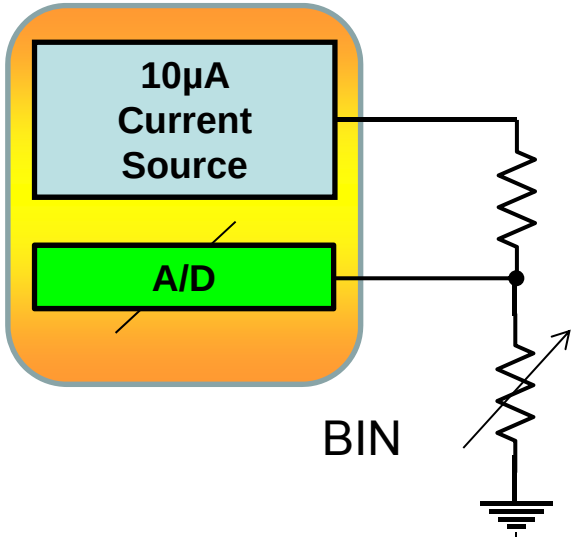
- Enhanced LED Dimming
  - Reduces heat
  - Increases LED life
  - Minimizes color shift
- Core independent operation
- Operation while in low power SLEEP



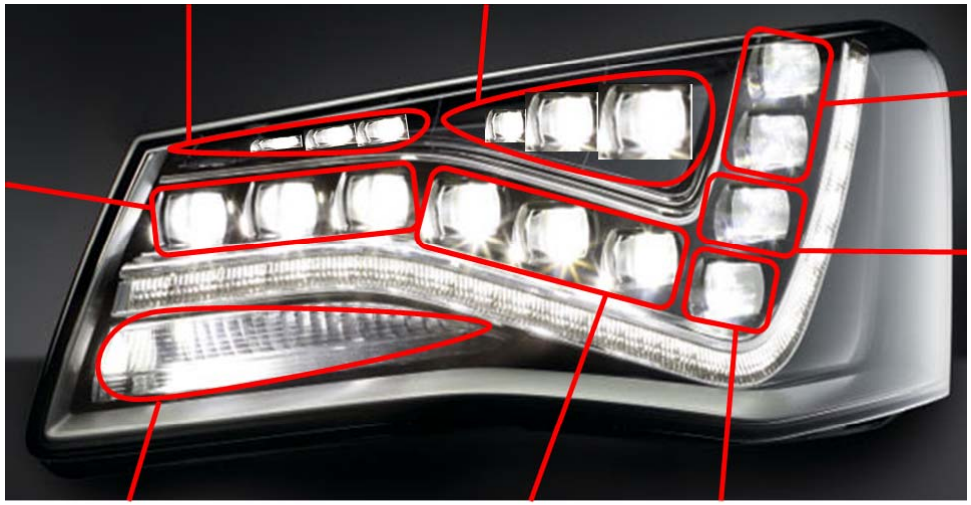
Adaptive Control

- **Intelligent Binning**
  - BIN resistors enable the selection of pre-defined coefficients, parameters and look-up tables
  - “LED Disconnected”detection
- **Bias options**
  - **Voltage biased**
    - Requires only one analog input
    - Easy to implement in conjunction with any MCU
  - **Current Source**
    - High precision due to compensation of parasitic resistance (e.g. connectors)
    - Better resolution allows support of more LED boards





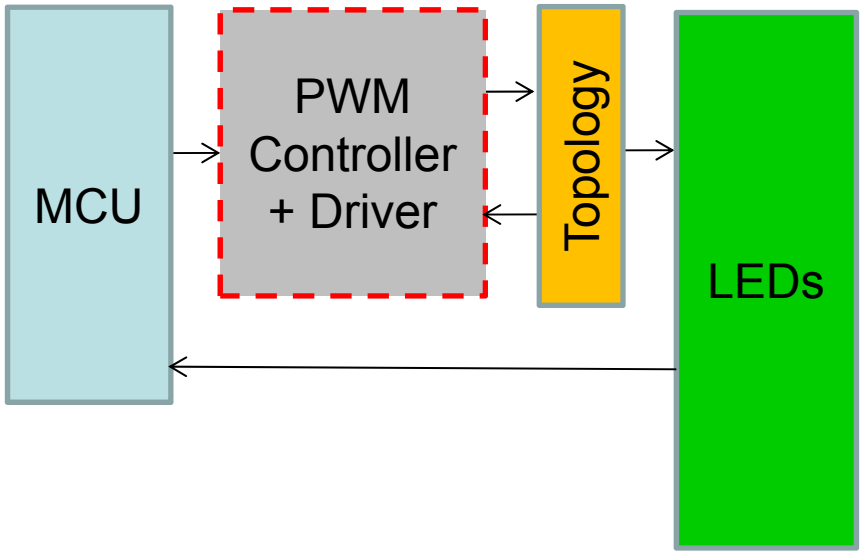
Hybrid Control (1)



Digitally-Enhanced Power Converter Product Concept

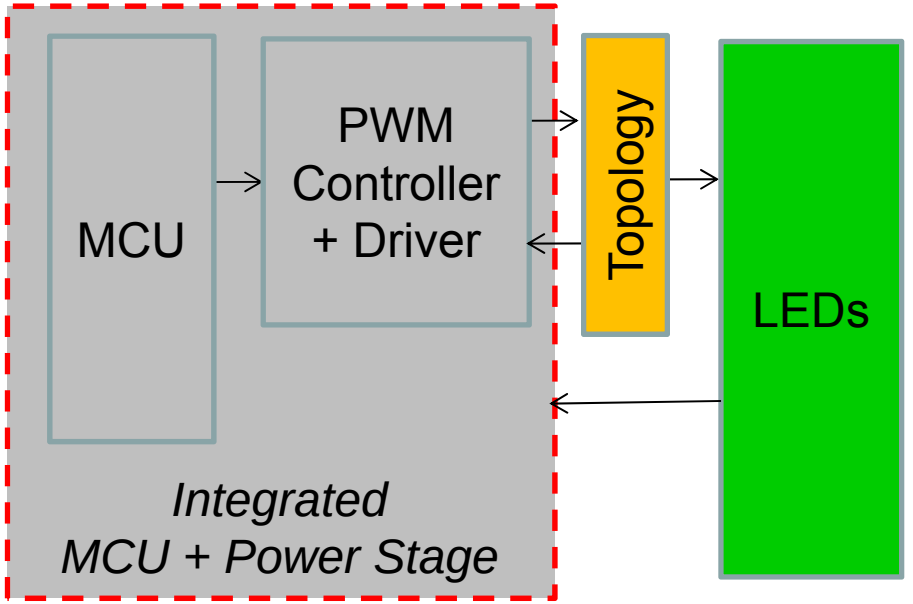
Analog Power Stage + External MCU

- External MCU + High Performance Analog Controller
- Modular design
  - Maximizes Flexibility
  - Minimizes time-to-market

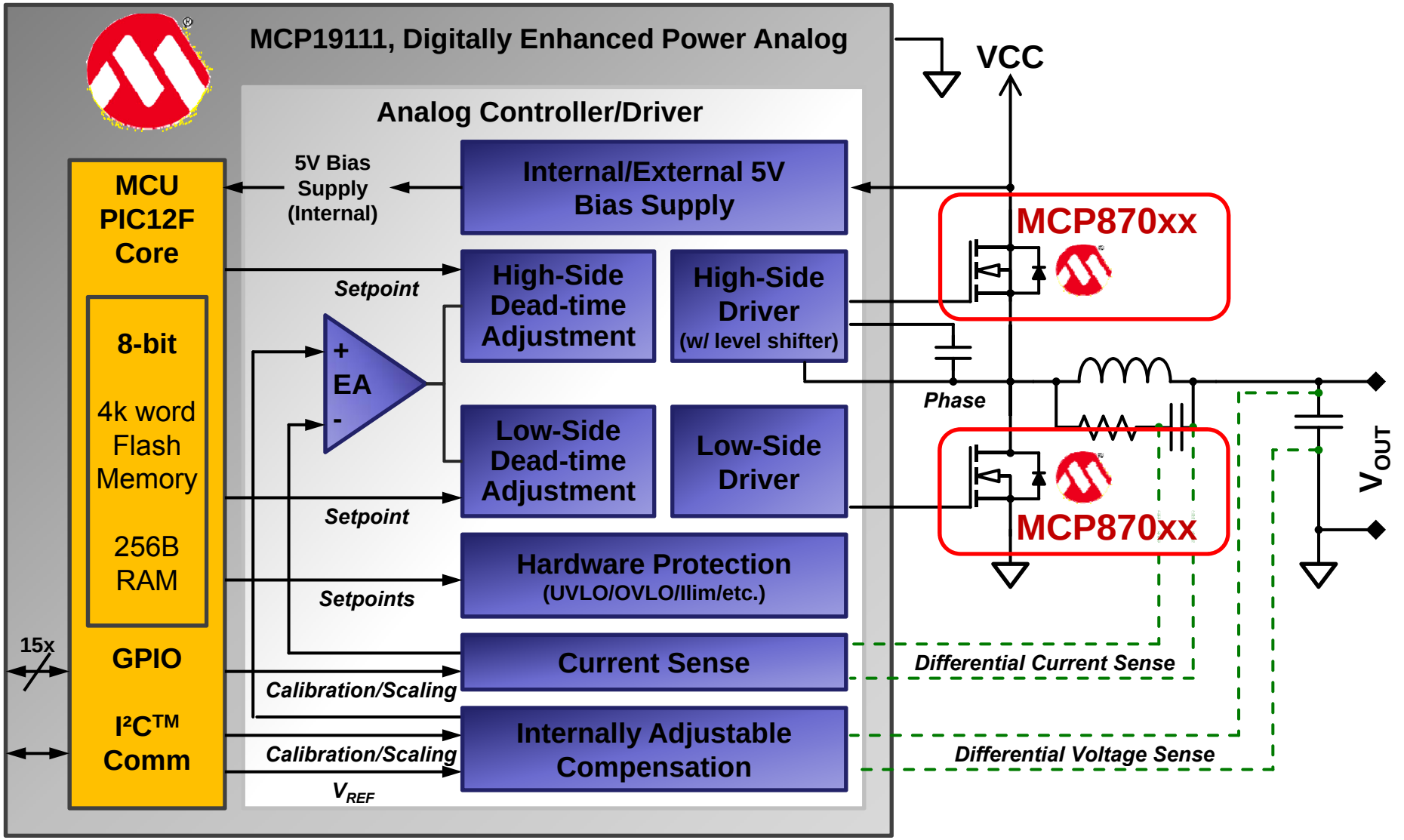


Integrated Analog + MCU Power Control

- Integrates PWM controller/Driver with Digital Core
- Single Package Solution
  - Reduces Design Complexity, Component Count, and footprint

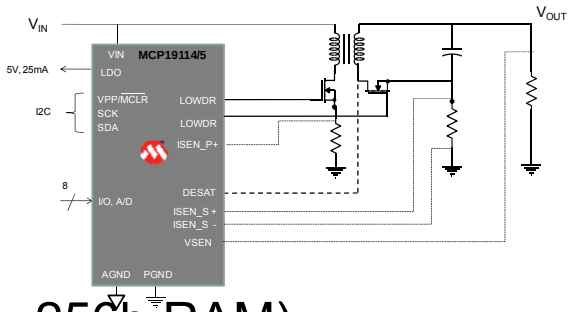


MCP19110/111
High Level Block Diagram



MCP19114/5
Key Features

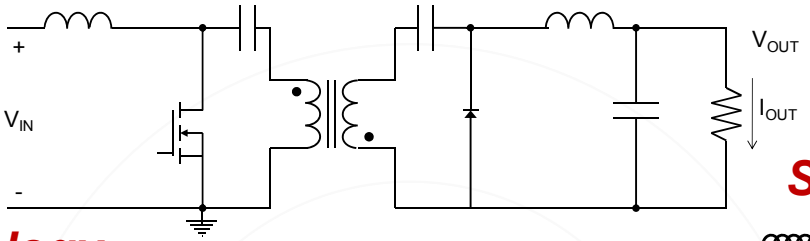
- **Wide Input voltage range: 5V to 42V**
- **Broad Topology Support**
  - Flyback, Boost, SEPIC, Ćuk
- **Integration**
  - Fully-Functional PIC® MCU (4k word Flash, 256b RAM)
  - High-Speed Analog PWM Controller
  - Integrated Mid-voltage LDO & Sync. Low-Side MOSFET drivers
- **Analog Adjustability**
  - Programmable Output Voltage, Soft Start, Switching Freq, Quasi-Resonant support, Protection Thresholds



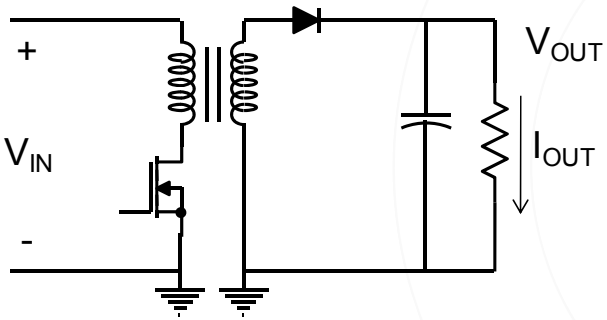
MCU + Low-Side Controller +Driver

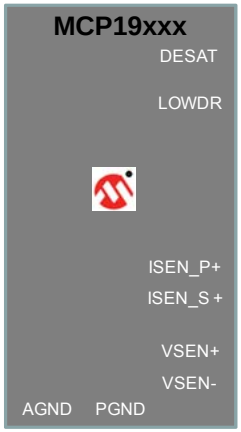
– Flexible Topology Support –

Ćuk Topology

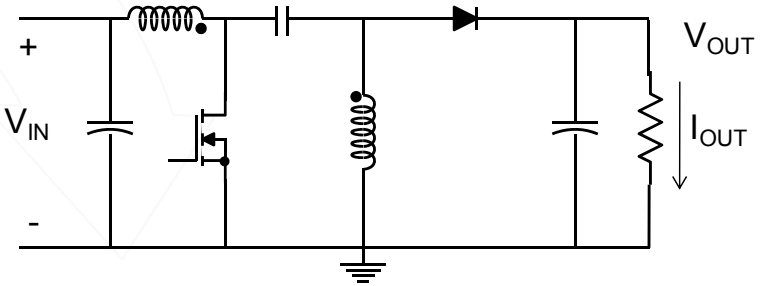


Flyback Topology

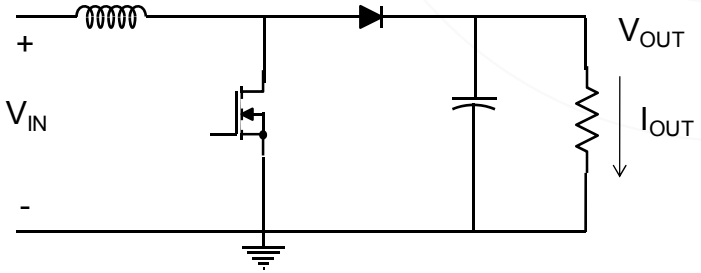




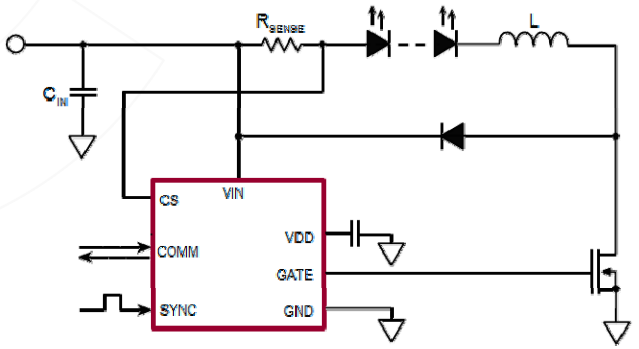
SEPIC Topology



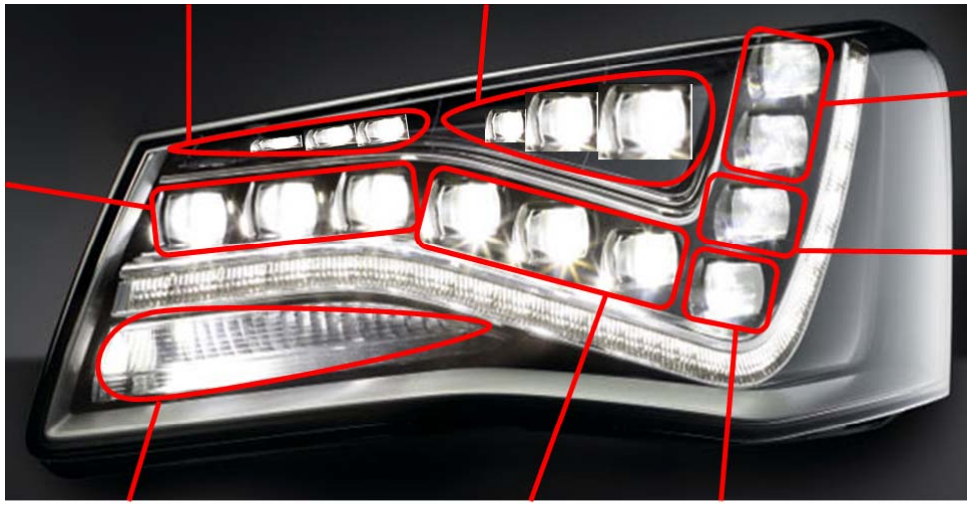
Boost Topology



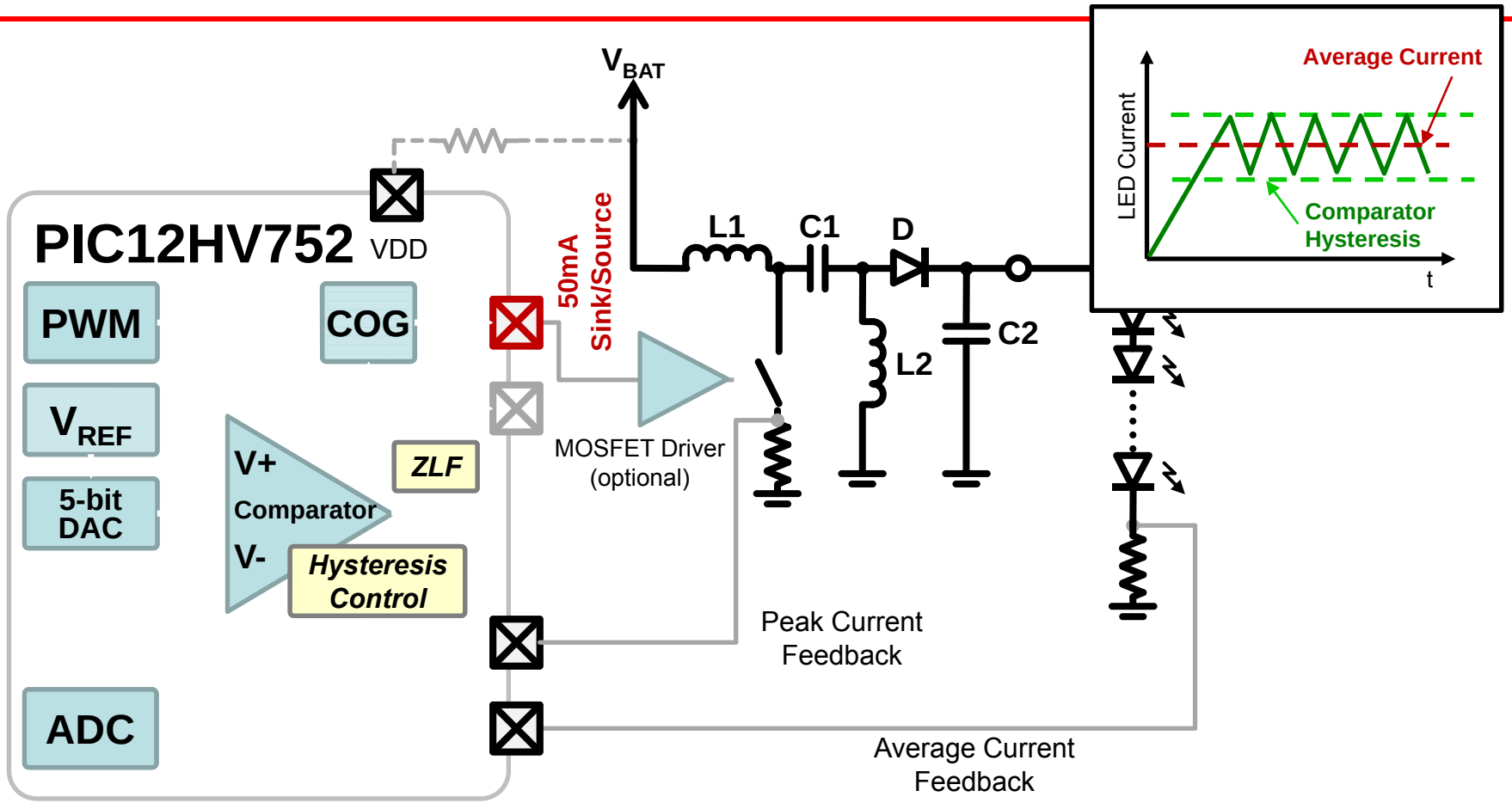
Low-Side Buck



Hybrid Control (2)



Low-End LED Drivers

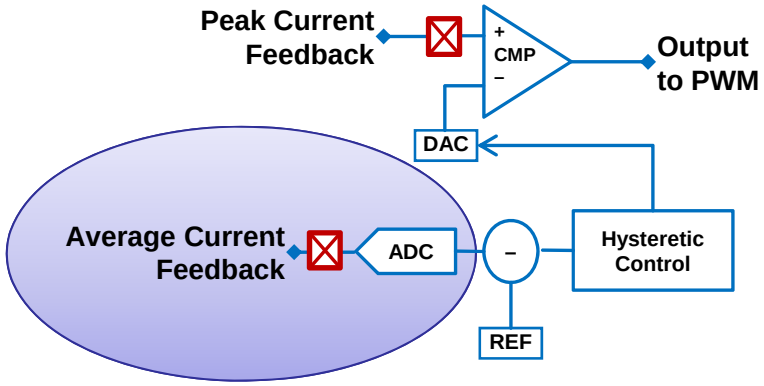


Example: LED Converter

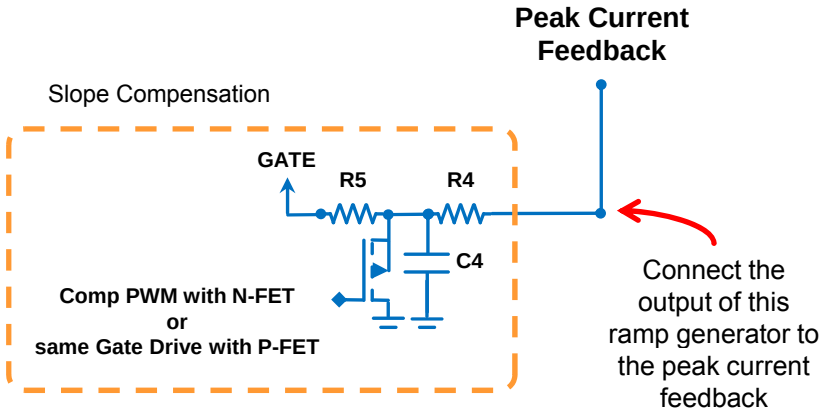
- *5b DAC (limited range) resolution allows for the use of smaller current sense resistor and eliminates need for external Op-amp*
  usage provides for less power consumption and better efficiency
- *COG frequency is determined by frequency of PWM, provides dead-band control for synchronous switches and blanking control*

Compensated Average Current Control with Peak Current Slope Compensation using PIC12F752

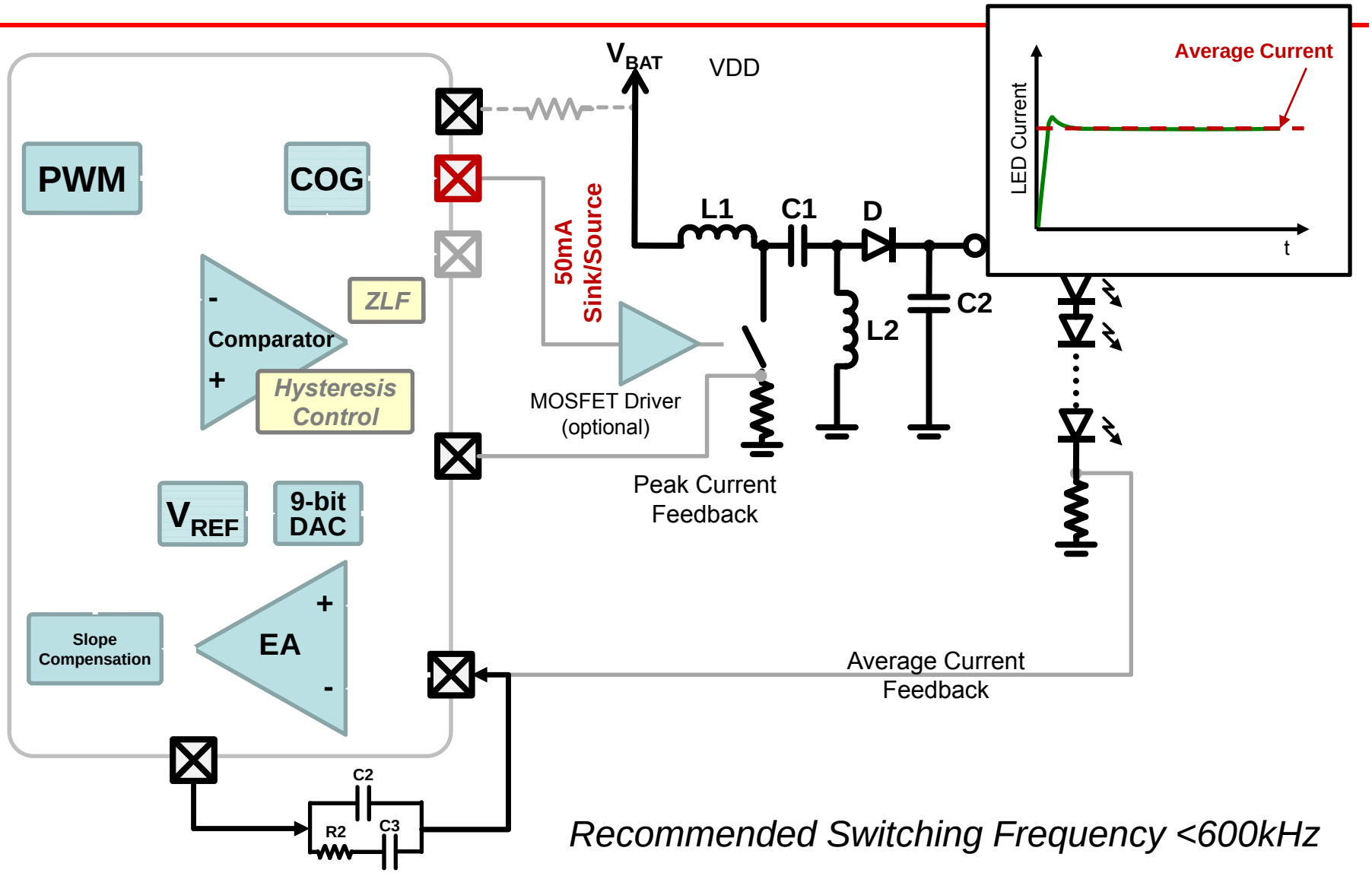
- **Advantages**
  - Easy implementation
  - Simple design
  - Minimum number of peripheral components required
  - Stable at constant loads and input voltage
  - Short circuit protected
- **Limitations**
  - Low control loop bandwidth
  - Permanent CPU load
  - Conditionally unstable at fast transients
  - At duty ratios >40% external peak current slope compensation required
- **Recommended Applications**
  - Battery powered systems (e.g. Flashlights)



Low Response Time



Enhanced Low-Cost Single String LED Drivers

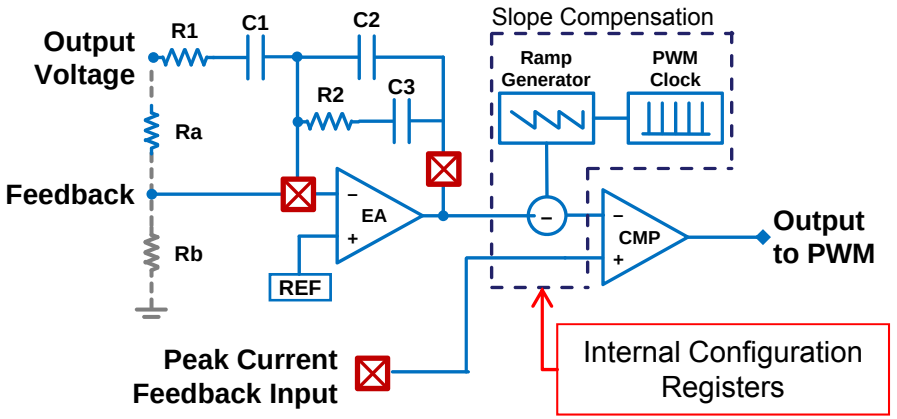


Recommended Switching Frequency <600kHz

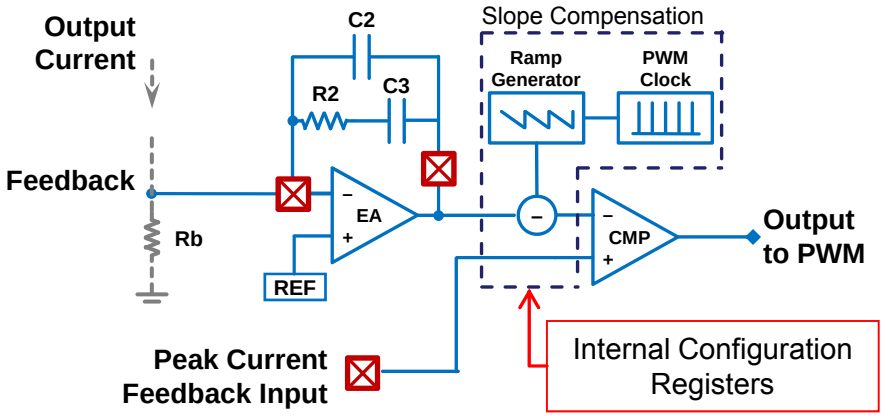
Hysteretic Average Current Control with Peak Current Slope Compensation using PIC16F753

- **Advantages**
  - Easy implementation
  - Simple design due to integrated features
  - Minimum number of peripheral components
  - Stable at dynamic loads and input voltage
  - Short circuit protected by default
  - High design flexibility due to external compensation network
- **Limitations**
  - (none)
- **Recommended Applications**
  - Forward & Flyback-Type DC/DC Converters
  - Current Sources (e.g. LED Drivers, Battery Chargers, etc.)

External Type III Compensation + Peak Current Mode Control /w internal Slope Compensation



External Type II Compensation + Peak Current Mode Control /w internal Slope Compensation



PIC16(L)F176x/177x Family Preview

- **A cost effective family of SMPS Microcontrollers**
  - 16 MHz Internal Oscillator (±1%) / 32 MHz Clock (8 MIPS Operation)
  - 14 to 44 pins
  - 4KW to 16KW FLASH (7kBytes to 28kBytes)
  - 128/256Bytes of High Endurance Flash
  - 512/1024/2048 Bytes RAM
  - 2.3 – 5.5V operation / 1.8 – 3.6V operation also available on ‘LF’ parts
  - Temperature range: -40 … +85°C (I-Temp) / -40 … +125°C (E-Temp)
  - AEC Q100 Grade B

- **Suited for a wide range of SMPS Applications**
  - Single-ended, Complementary and Fully-Bridge PWM
  - Fixed Frequency, Resonant and Quasi-resonant Operation
  - Flexible, runtime-adjustable analog feedback loop

- **LED Driver Optimizations**
  - Core Independent Hardware Dimming Engine
  - Core Independent Fault Detection
  - Enhanced Communication Features

- **General Purpose Functionality**
  - 14, 20, 28 and 44 pin footprints
  - Communications modules
    - EUSART (LIN), MSSP (SPI and MI2C)
  - nanoWatt XLP Low Power Technology

Function Enablement:

Basic Switching Regulator Mimic - Description

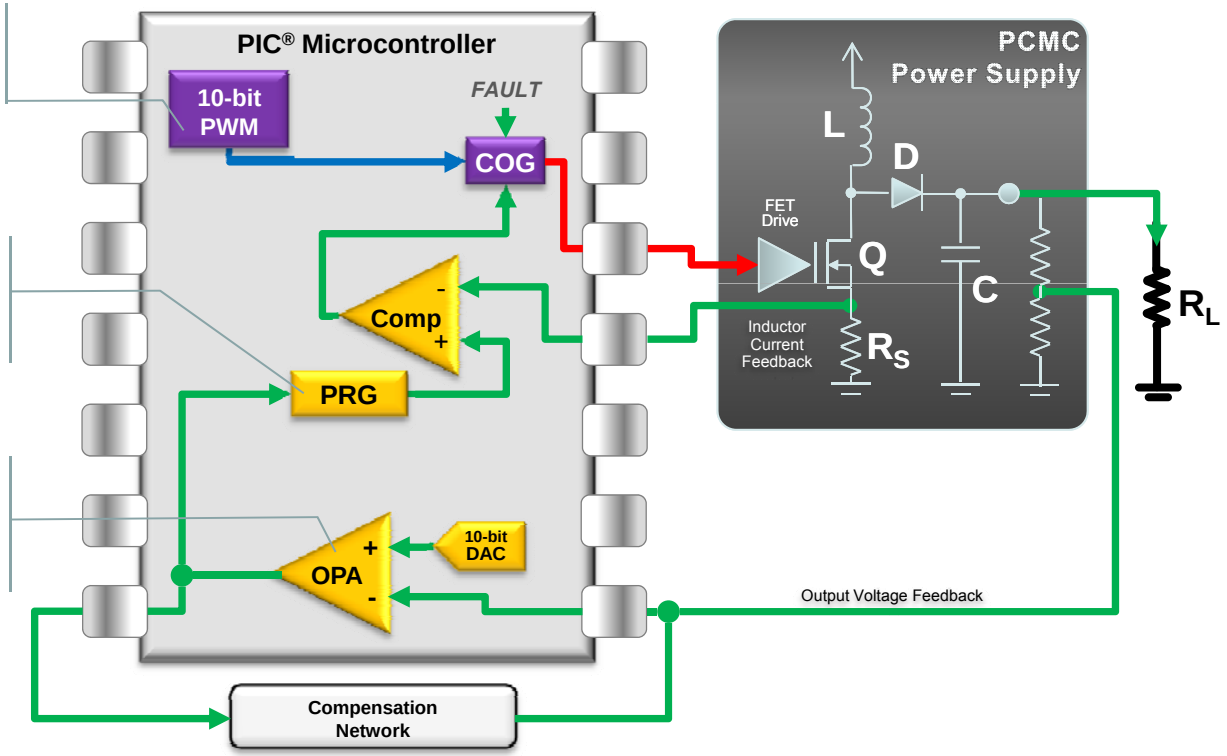
Standard Switching Regulator Mimic for Peak Current Mode Control (PCMC)

- **Peak-Current Mode Switching Regulator Mimic Peripheral Set**
  - PWM: 10- or 16-bit resolution to pre-set periods and duty ratio ranges
  - COG: Handles the port control to generate complementary waveforms, dead-time insertion and override shut-down
  - DAC: 10-bit resolution on the selected reference source to generate the reference voltage for the error amplifier
  - OPA: General purpose op-amp used as inverting error amplifier (externally compensated)
  - PRG: Programmable Ramp Generator to apply compensation ramps to the PCMC comparator reference input
  - COMP: Fast analog comparator (<50ns) is used as Peak Current Mode Comparator directly truncating the active on-time on a cycle-by-cycle basis

PWM Generator
10-bit PWM for generating power supply switching frequency

PCMC Slope Compensation
Programmable Ramp Generator for runtime-adjustable peak current mode slope compensation

Error Amplifier
Rail – Rail OpAmp as error amplifier with output disable for improved control loop performance minimizing LED current overshoot



Function Enablement:

Precision LED Dimming Engine - Description

LED Dimming Engine

Interconnection of 10-bit/16-bit PWM, DSM, & OpAmp

- **Stage 1: Overshoot Control**
  - PWM: 10-bit SMPS & 16-bit Dimming
  - Data Signal Modulator (DSM):
    - Synchronizes PWM switching signals
  - Combinatorial Logic Cell (CLC)
    - Optional to combine, invert, delay or latch control signals
- **Stage 2: Decay Control**
  - Op Amp:
    - Tri-stated to prevent saturation
  - 16-bit PWM:
    - Freezes OpAmp compensation during "OFF"
    - LOAD disconnect for fast output "OFF"

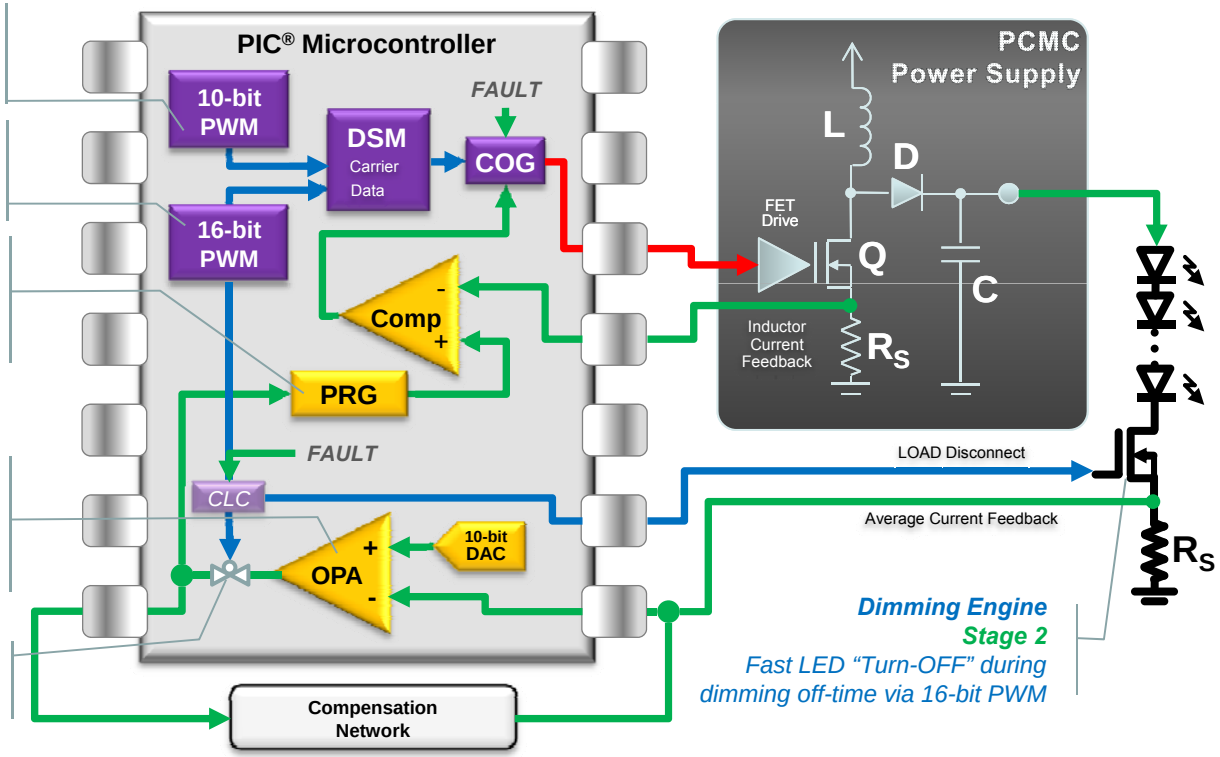
Dimming Engine
Stage 1
10-bit PWM for generating power supply switching frequency

Dimming Engine
Stage 1 & 2
16-bit Dimming control signal generation

Dimming Engine
Stage 1
Programmable Ramp Generator for runtime-adjustable peak current mode slope compensation

Dimming Engine:
Stage 1
Rail – Rail OpAmp as error amplifier with output disable for improved control loop performance minimizing LED current overshoot

Dimming Engine
Stage 2
Compensation "Freeze" via tri-state OpAmp



Dimming Engine
Stage 2
Fast LED "Turn-OFF" during dimming off-time via 16-bit PWM

Function Enablement:

Fault Detection and Protection - Description

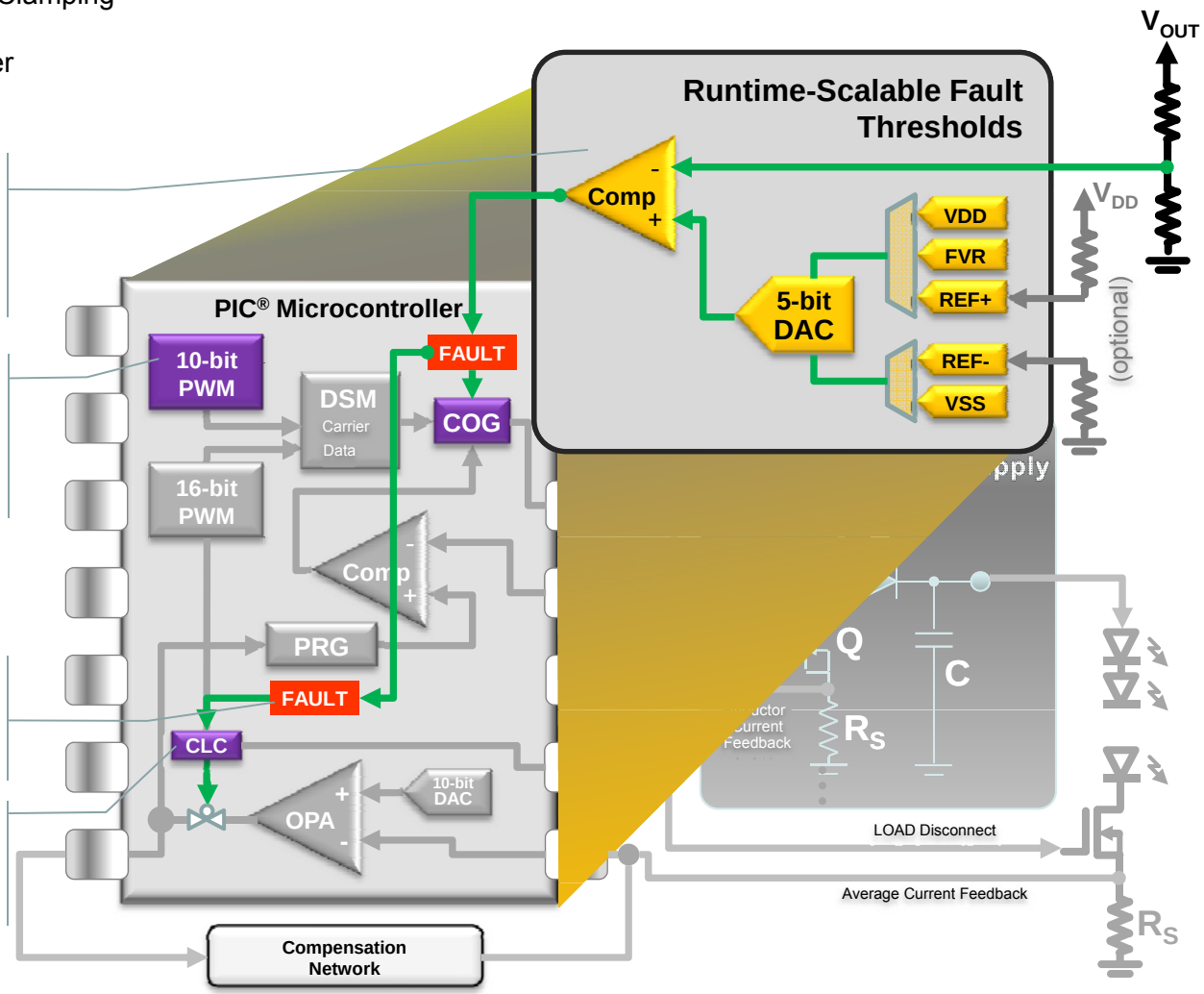
- **Additional SMPS Channel Protection Features**
  - PWM Duty Cycle or Frequency Clamping
  - Secondary Analog Comparator
  - 5-bit Digital-To-Analog Converter (DAC)
  - Configurable Logic Cell (CLC)

Analog Comparator /w 5-bit DAC with flexible Reference Inputs
Allows runtime threshold adjustment within a reference voltage window between VDD and VSS with 5 bit resolution

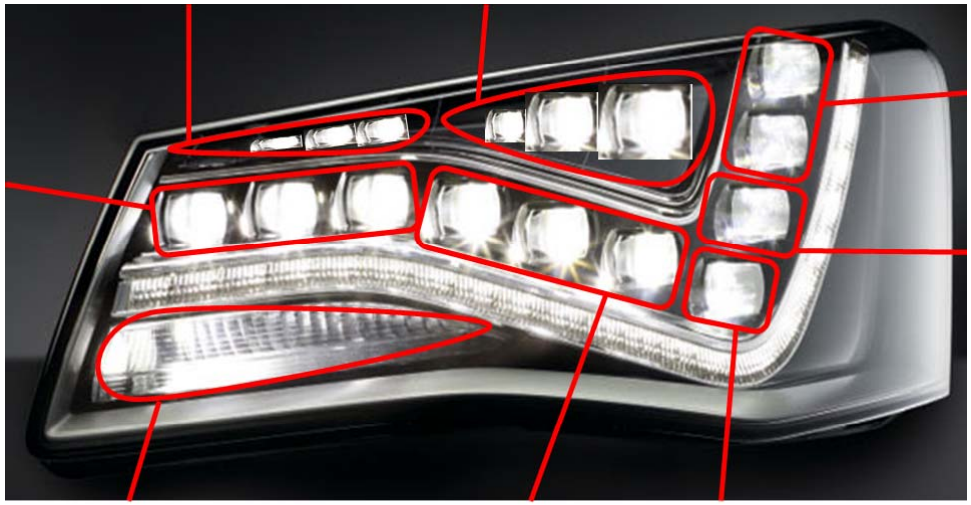
PWM Duty Cycle and Frequency Clamping
Digital PWM generators offers programmable clamping of duty cycles and/or frequencies by default. No further EA output clamping is required

Distributed Fault Signals
FAULT signals can be distributed internally to shut down different peripheral modules simultaneously

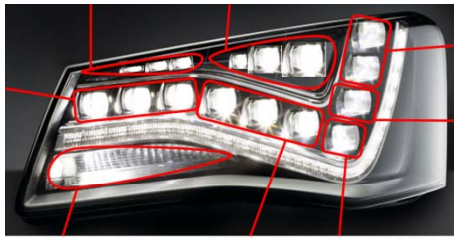
Handling Complex Fault Conditions
Configurable Logic Cells can be used to trigger/filter on complex fault conditions



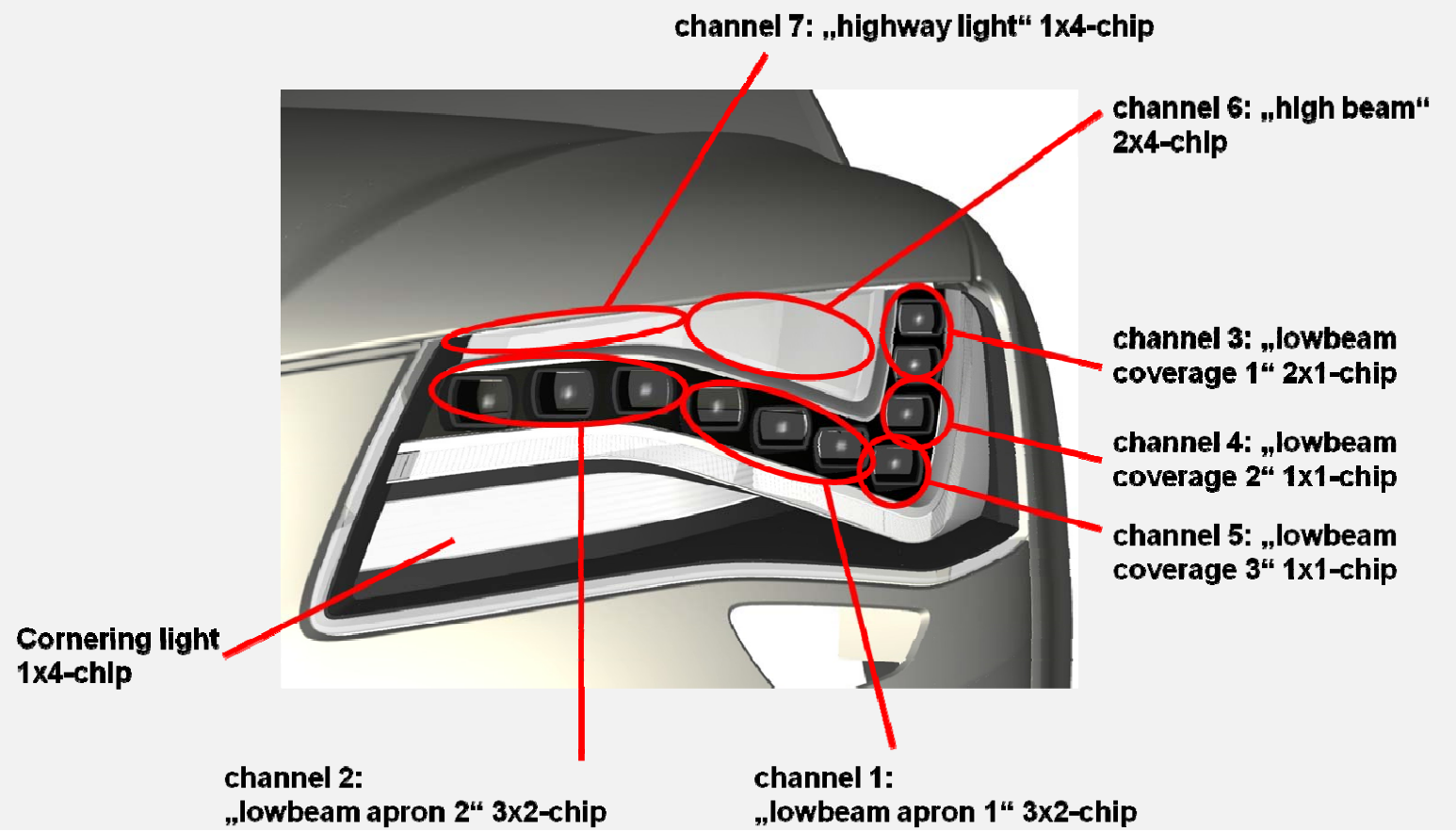
Automotive Headlight



Matrix Headlights



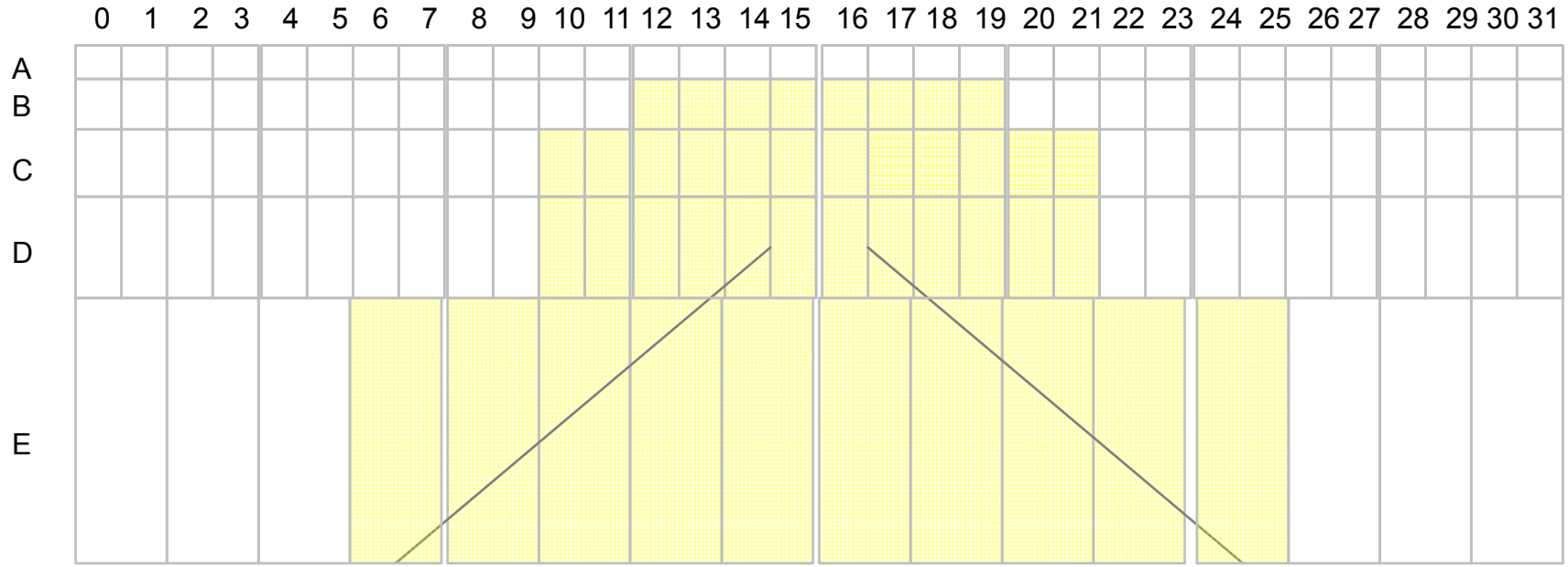
Headlight Configuration


channel 7: „highway light“ 1x4-chip
channel 6: „high beam“ 2x4-chip
channel 3: „lowbeam coverage 1“ 2x1-chip
channel 4: „lowbeam coverage 2“ 1x1-chip
channel 5: „lowbeam coverage 3“ 1x1-chip
Cornering light 1x4-chip
channel 2: „lowbeam apron 2“ 3x2-chip
channel 1: „lowbeam apron 1“ 3x2-chip

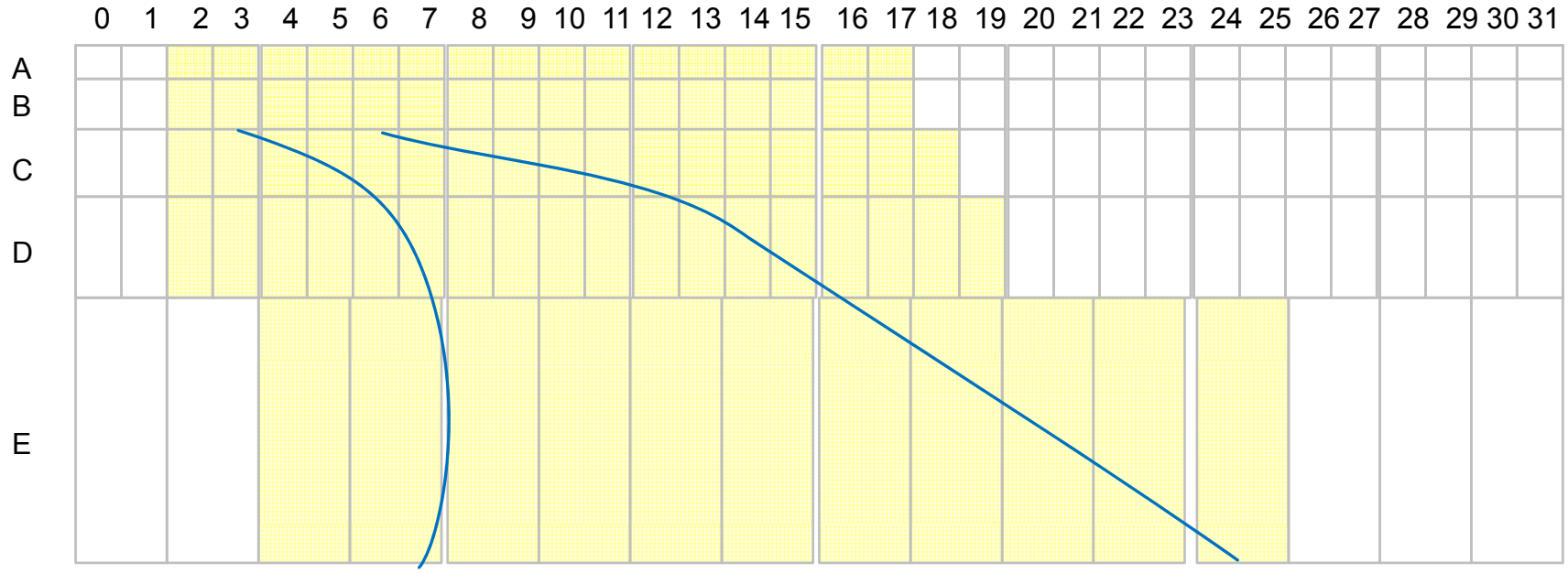
Headlight Configuration

CH No.	Name	No of LED Boards	LEDs per Substrate	Length of LED String	Luminous Flux per LED String [lm] (typ.)	LED Type	Typical Forward Voltage Drop [V] per Substrate	DV_F @ -40°C [V]	max. Forward Voltage Drop [V] per LED String	Nominal LED Current [mA]
1	low beam apron 1	3	2	6	900	Osram Ostar LE UW D1W201	7.2	1.0	24.6	700
2	low beam apron 2	3	2	6	900	Osram Ostar LE UW D1W201	7.2	1.0	24.6	700
3	low beam coverage 1	2	1	2	300	Osram Ostar LE UW D1W101	3.7	0.5	8.4	700
4	low beam coverage 2	1	1	1	150	Osram Ostar LE UW D1W101	3.7	0.5	4.2	700
5	low beam coverage 3	1	1	1	150	Osram Ostar LE UW D1W101	3.7	0.5	4.2	700
6	high beam 1	2	4	8	1200	Osram Ostar LE UW D1W401	14.1	2.0	32.4	700
7	high beam 2	1	4	4	600	Osram Ostar LE UW D1W401	14.1	2.0	16.2	700
8	cornering light	1	4	4	600	Osram Ostar LE UW D1W401	14.1	2.0	16.2	700

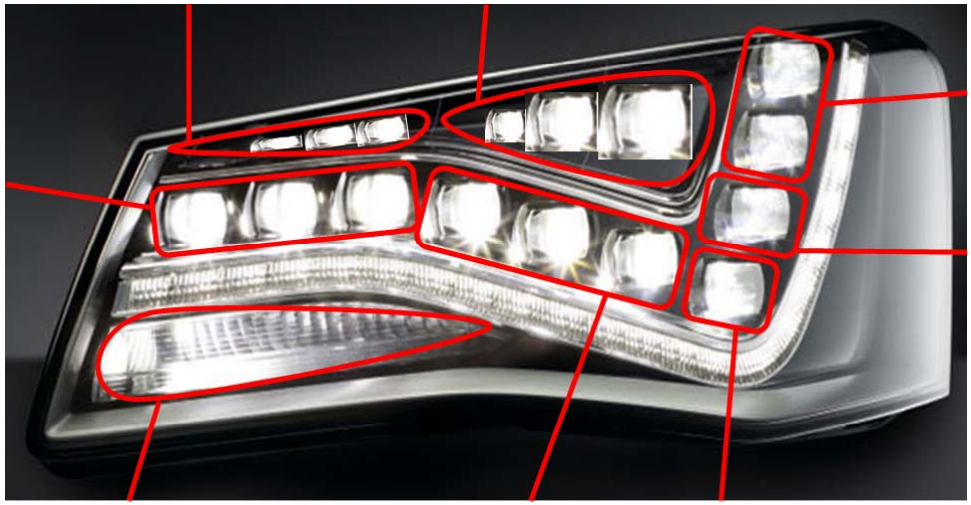
Light Distribution Concept



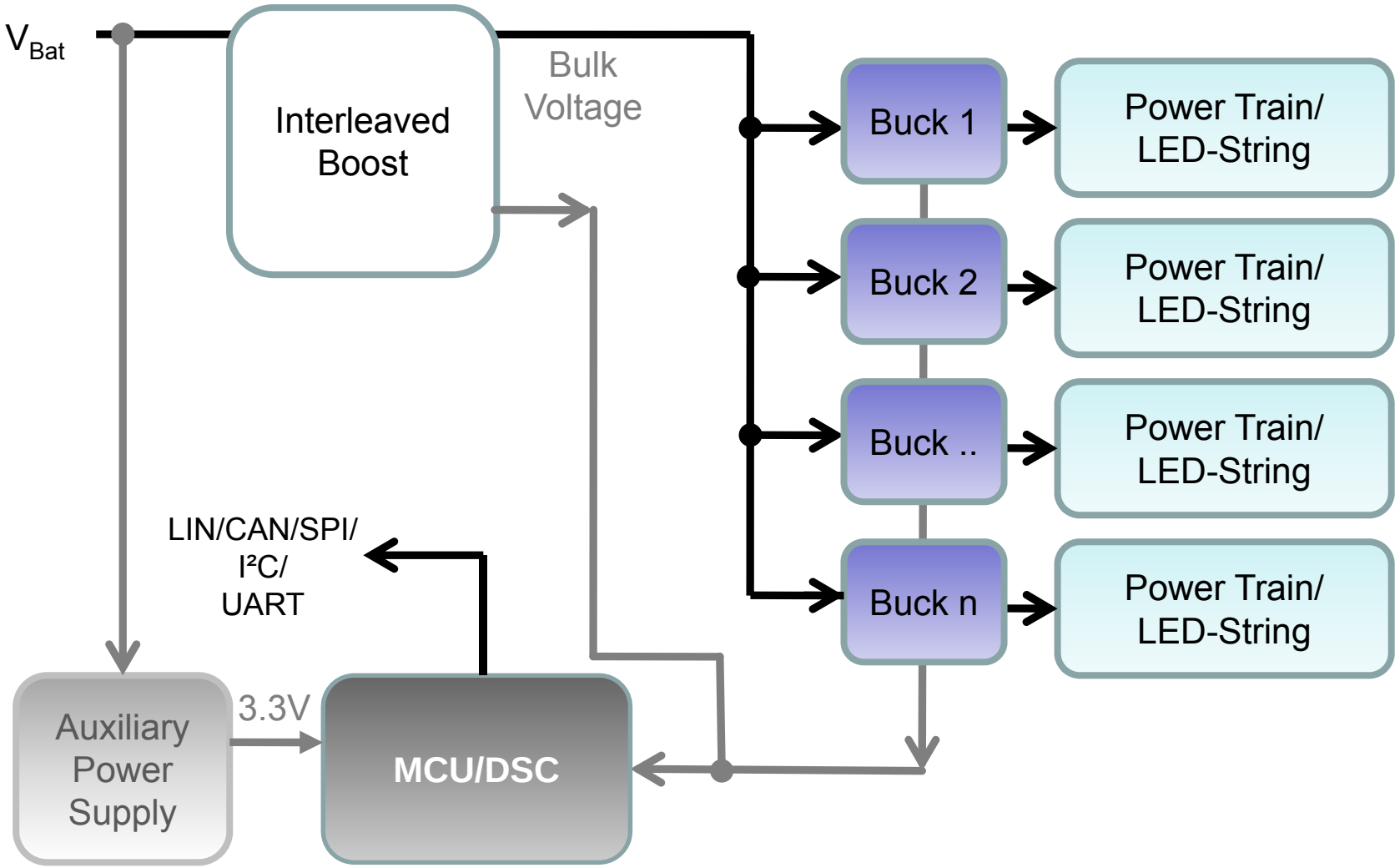
Light Distribution Concept



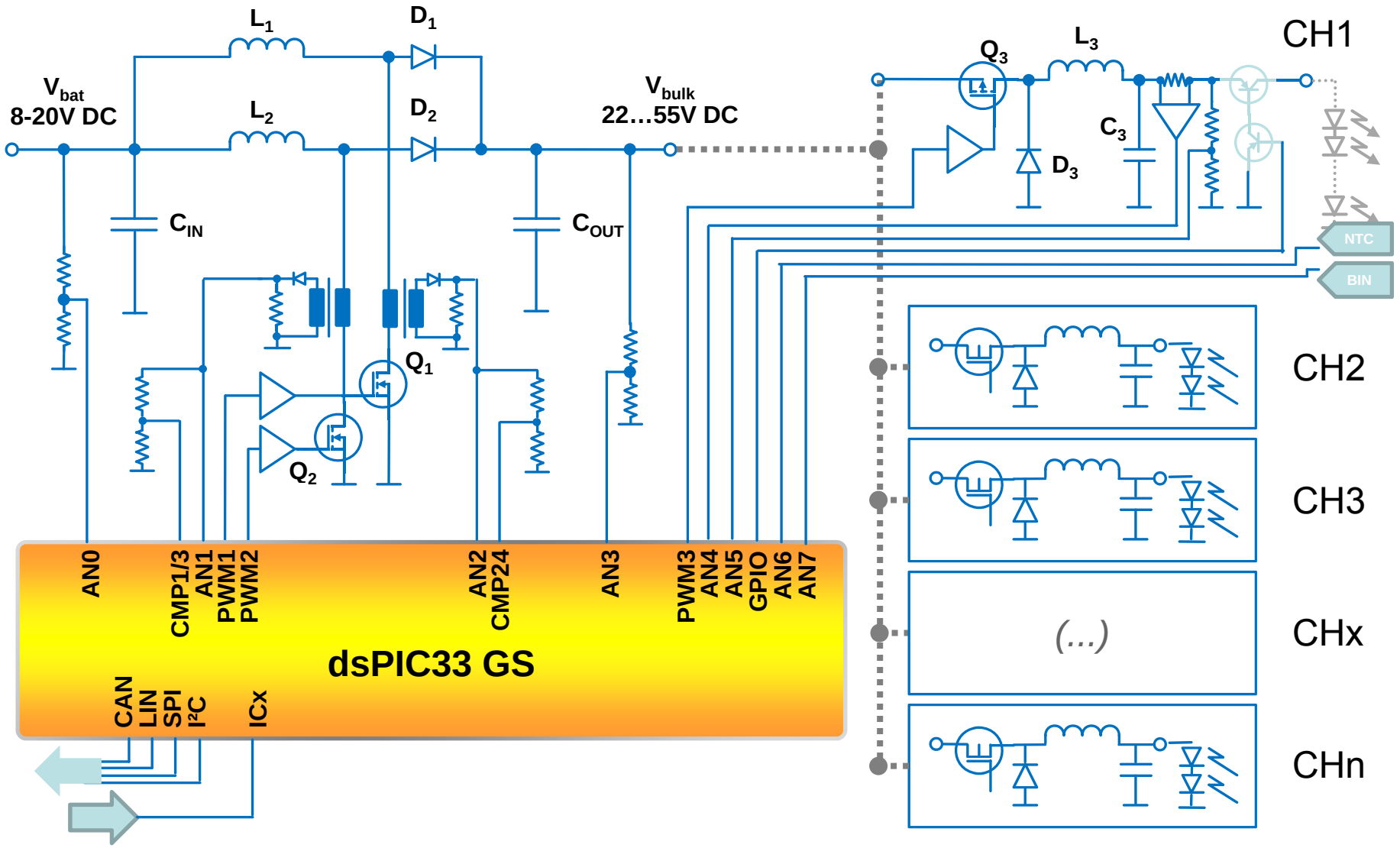
Matrix Headlamp Block Diagram



High-Level Block Diagram



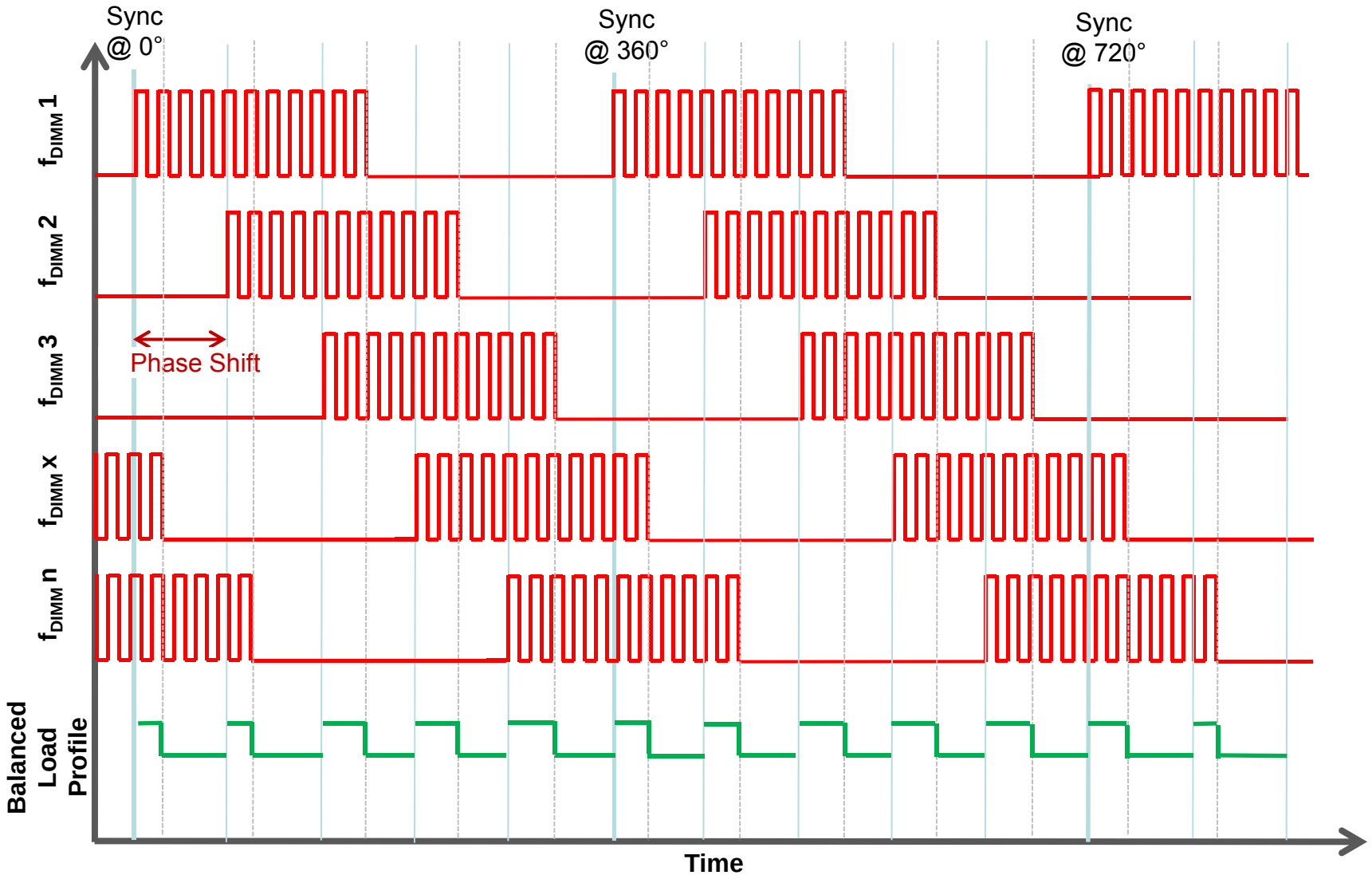
Pre- and Post Regulation Stages



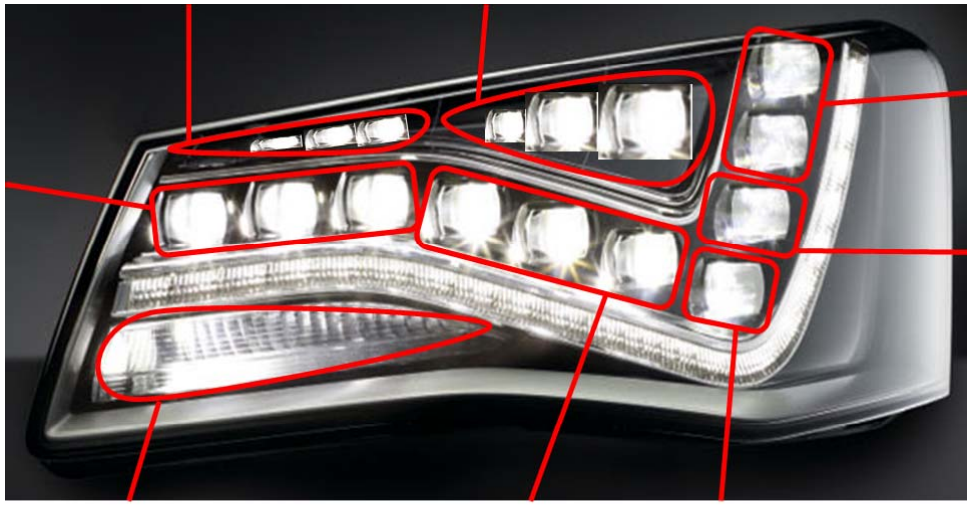
Overall Control Scheme

- One dsPIC33FJ64GS606 controls the interleaved Boost converter and eight Buck converters in parallel
- Due to the low dynamic of the LED output current, the Boost converter control loops are dominant
- Additional tasks, such as low frequency dimming, temperature compensation, CAN communication and fault handling, are placed on different priority levels to ensure deterministic operation

Enhanced Dimming of Multiple Channels

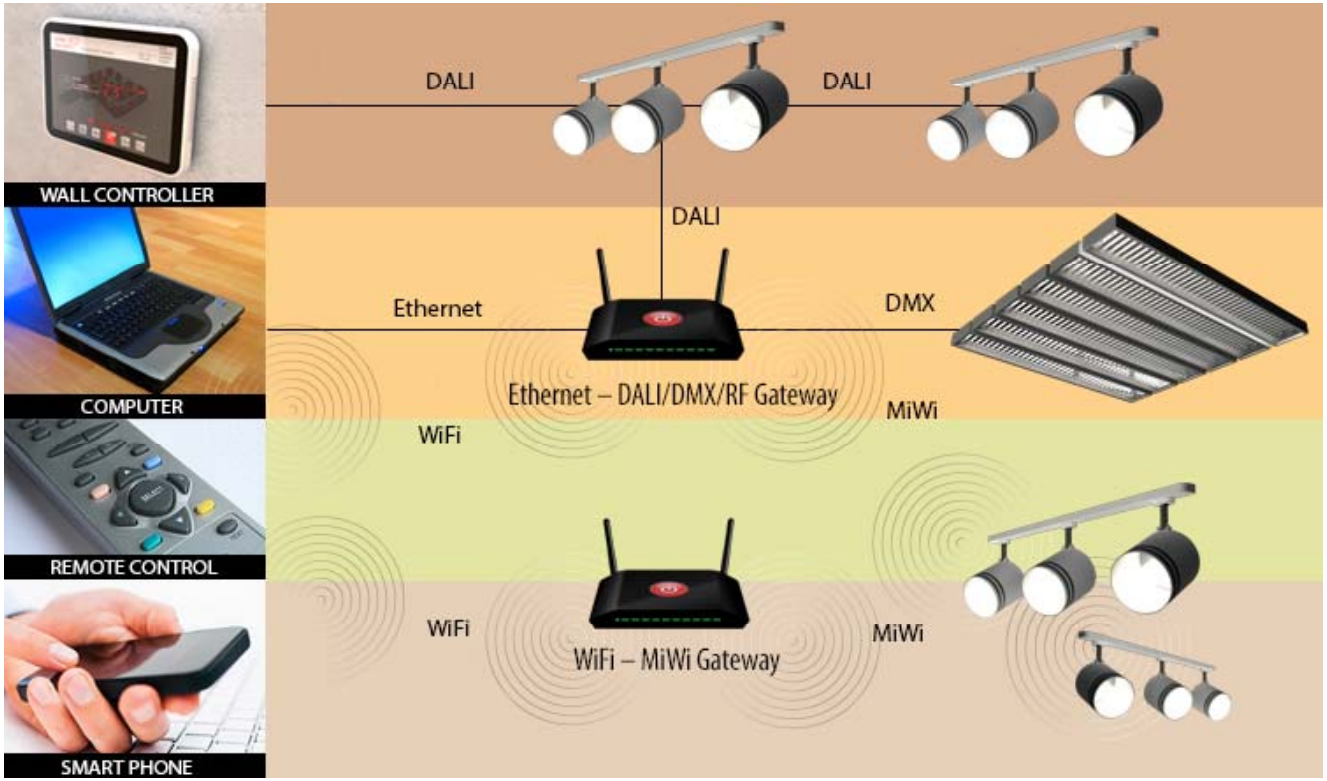


Communication



Lighting Control
Networking & Communication

Wired Protocols
- DALI
- DMX512A
- BACnet
- 0-10V
- PLC
- LIN
- CAN
- RS232/RS485
- USB LS/FS
- Ethernet



Wireless – Transceivers and Modules
- Wi-Fi® 802.11 modules, Bluetooth®
- ZigBee®, RF4CE, MiWi™ 802.15.4 modules
- Stacks for PIC® MCUs
- Infrared/IrDA®

Lighting Control
Wall Controllers & Remotes

Legacy Control

Non-Intelligent Lighting Control
- Mechanical Interface
- Limited Luminaire Control
- Lacks User Feedback
- Lacks Communication
- Lacks Product Differentiation

Microchip Human Interface Options

mTouch® – all PIC® MCU families
- Capacitive buttons and sliders
- Metal over Cap capability
- Projected Capacitive capability

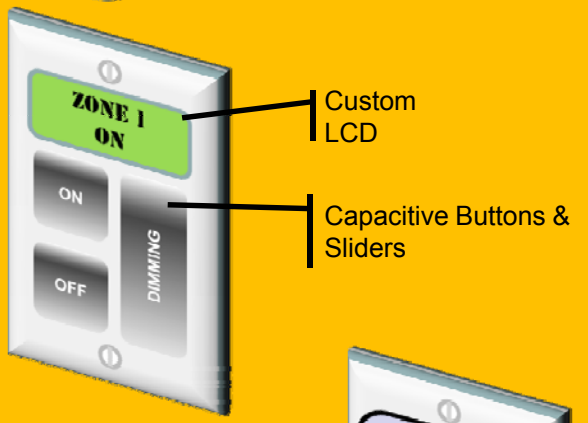
Segmented LCD – PIC16, PIC18, PIC24
- Up to 480 segments
- Low power display modes
- Contrast control

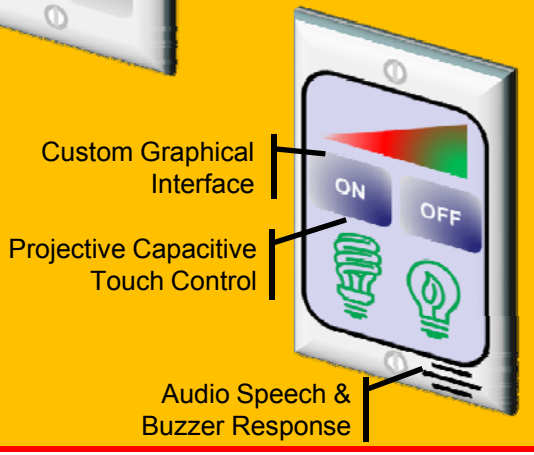
Graphics – PIC24, PIC32, dsPIC® DSC
- Integrated graphics controllers
- Direct drive for QVGA and W-QVGA
- FREE graphics library and designer tool

Gesture – MGC3130 + all PIC MCU families
- Recognition of 3D hand gestures and x/y/z positional data
- Very low power design

Communication – all PIC MCU families
- Intelligent luminaire control
- DALI, DMX512, LIN/CAN, Wireless, others…
- FREE code libraries

Intelligent Control





DALI

DALI – “Digital Addressable Lighting Interface”

- Designed primarily for Commercial & Industrial lighting
- 2-wire connection and offers individual lamp or group addressability in a bus configuration

FREE DALI Firmware Library

- ‘C’ based firmware library
- Control Device (master) & Control Gear (slave) libraries
- Automated Commissioning
- Simple API for ease of use
- Firmware implementation on any 8-bit PIC® Microcontroller
  - PIC Microcontroller Requirements
    - (1) 8-bit timer / (1) 16-bit timer
    - EEPROM or Emulated EEPROM (self-write Flash)
    - ~4KW Flash Program memory footprint (final code size TBD)
- Compliance
  - IEC 62386-101 (DALI general system requirements)
  - IEC 62386-102 (DALI general system requirements – control gear)
  - Future support for IEC 62386-2xx implementation (particular requirements for control gear; eg. LED, Fluorescent, etc.)

Downloadable at www.microchip.com/lightingcomms

DMX512A

DMX512 – “Digital Multiplex with 512 pieces of information”

- Designed primarily for Theatrical & Architectural lighting
- Increased reliability over that of 0-10V

FREE DMX512A Firmware Library

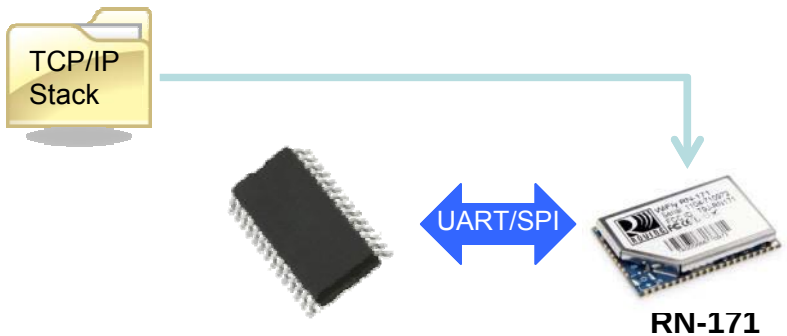
- ‘C’ based firmware library
- Controller (master) & Receiver (slave) in a single library
- Simple API for ease of use
- Firmware implementation on any PIC® Microcontroller
  - PIC Microcontroller Requirements
    - (1) EUSART
    - (1) 16-bit timer
    - ~1W Flash Program memory footprint
- Compliance
  - ANSI E1.11-2008 (USITT DMX512-A, Asynchronous Serial Digital Data Transmission Standard for Controlling Lighting Equipment and Accessories)

Downloadable at www.microchip.com/lightingcomms

Bluetooth® Portfolio

	RN41 / 41N	RN42 / RN42N	RN4020	BM77
Type	Class 1 Bluetooth 2.1	Class 2 Bluetooth 2.1	Bluetooth LE	Bluetooth Dual Mode (Classic & LE)
Interfaces	← UART / USB →		UART	UART
Profiles	← SPP / HID / iAP / HCI →		GATT / Health, Fitness / Proximity, Etc. / Custom data	GAP / SDP / SPP / GATT
Power	← 3.3 VDC →			
Antenna	Ceramic chip onboard (RN41N - no antenna)	PCB (RN42N - no antenna)	PCB	Ceramic chip onboard
Size (mm)	13.4 x 25.8 x 2.0		11.5 x 19.5 x 2.5	22 x 12 x 2.4
Certification	FCC / IC/ CE / AUS / JP	FCC / IC/ CE / AUS / JP / Korea / Taiwan	FCC / IC/ CE / AUS / JP / Korea / Taiwan	FCC / IC / JP

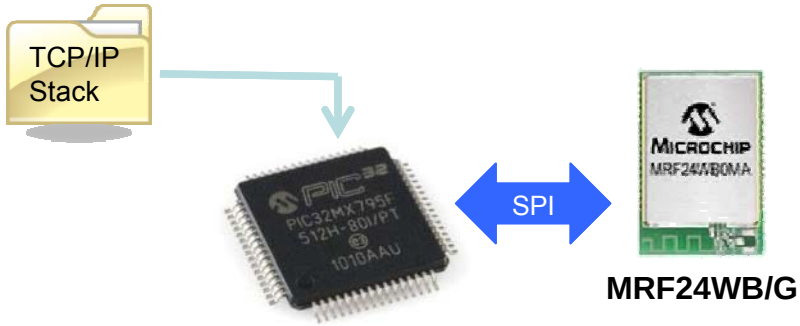
Product Portfolio



RN-171

KEY FEATURES

- TCP/IP stack onboard module
- Soft AP Mode
- Ultra-low power, fast connect (<100ms)
- True 802.11 b/g
- Works with any microcontroller
- Simple Services
  (http client, FTP, SNTP, WPS)



MRF24WB/G

KEY FEATURES

- Microchip TCP/IP stack
- 802.11 b & b/g
- Footprint compatible
- Microchip dev environment
- Richer services: HTTP Server
- EAP, Wi-Fi Direct, WPS

2.4GHz Product Portfolio
IEEE 802.15.4

802.15.4 Transceiver IC

- MRF24J40

802.15.4 Modules

- MRF24J40MA +0dBm
- MRF24J40MB +20dBm, PCB Ant
- MRF24J40MC +20dBm, Ext Ant

IEEE 802.15.4 Modules

MRF24J40MA/MB/MC

- 2.4 GHz IEEE 802.15.4™ Compatible
- Supports Microchip Wireless stacks:
  - ZigBee® , MiWi™ Development Environment

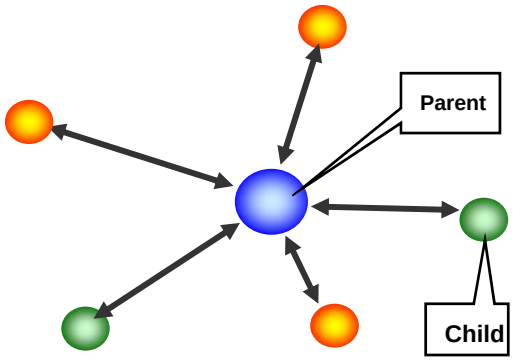
- Module Features:
  - Integrated PCB antenna or external Antenna
  - FCC (U.S.A.), IC (Canada), and ETSI (Europe) certified
  - Transmit Power / Receiver Sensitivity

Transmit Power	Receiver Sensitivity
MA = +0 dBm	MA = -94 dBm
MB = +20 dBm	MB = -102 dBm
MC= +20 dBm	MC= -108 dBm

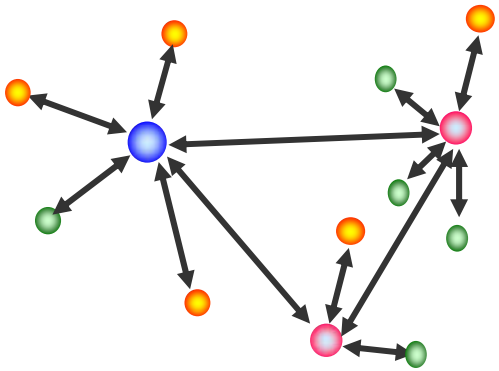
MiWi™ Protocol Stacks
Cost Effective Wireless

- Customizable
- No Alliance Membership
- No Alliance Certification
- Full Source Code Available
- 2.4GHz & Sub-GHz Support
- 150 – 4000 ft range (per hop)
- Self Healing Network
- FCC RF Certified Modules

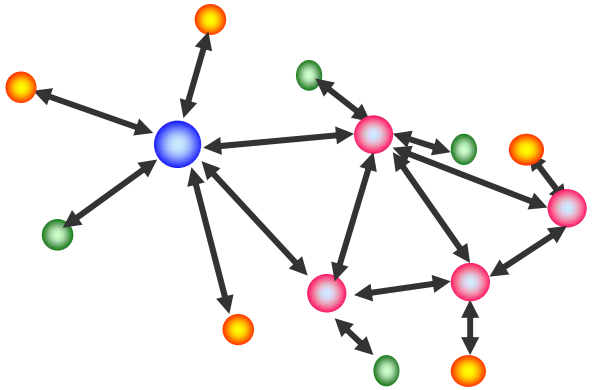
MiWi™ P2P
- Simple Star Network
- Near Limitless Nodes
  - Based on CPU resources
- ~4KB Code Size



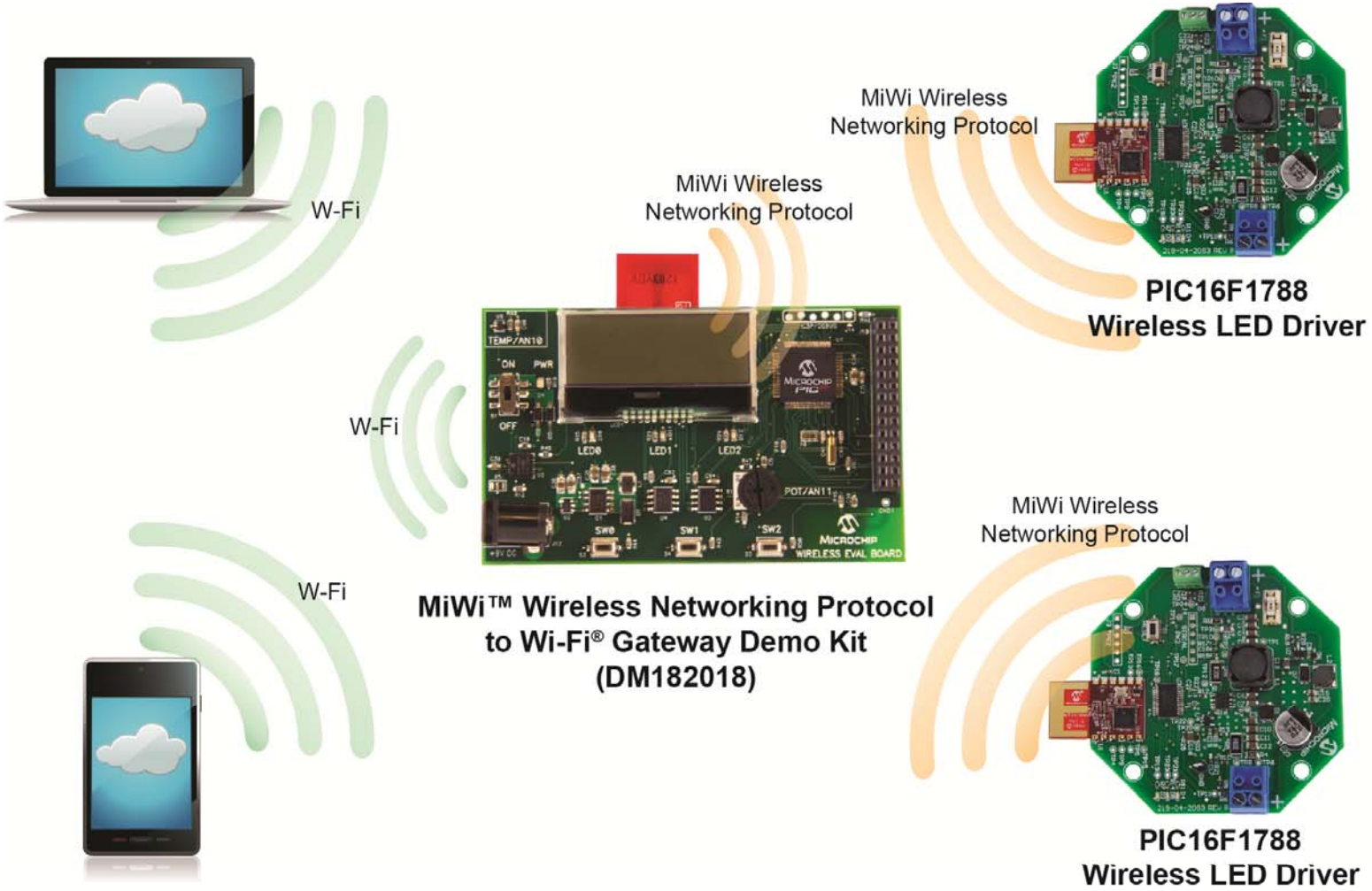
MiWi
- Mesh Network
- Up to 4 hops routing
- Up to 1000 nodes
- ~16KB Code Size



MiWi PRO
- Mesh network
- 64 hops routing
- Up to 8000 nodes
- Network Freezer
- ~25KB Code Size

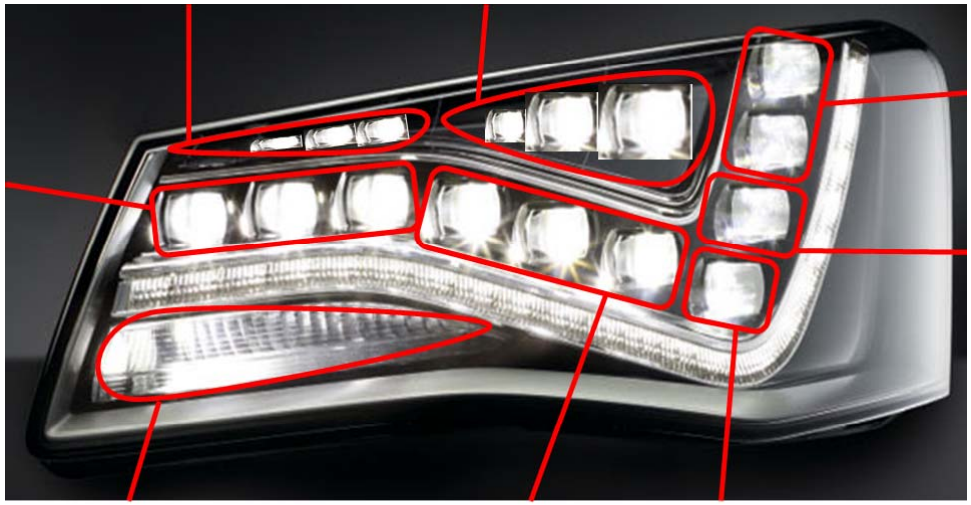


MiWi™ Wireless Lighting Topology



Any Questions?

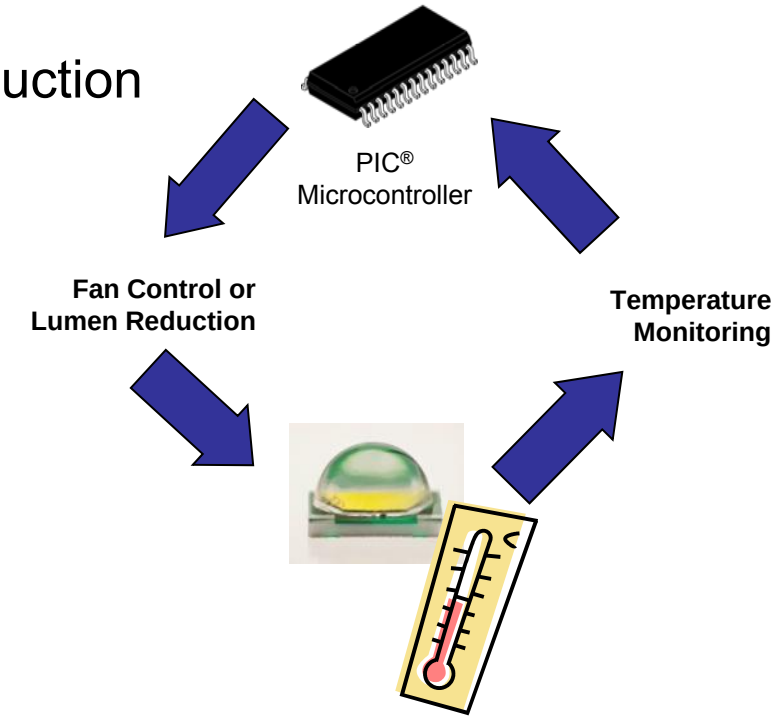
Appendix



Thermal Management

Luminaire Thermal Management

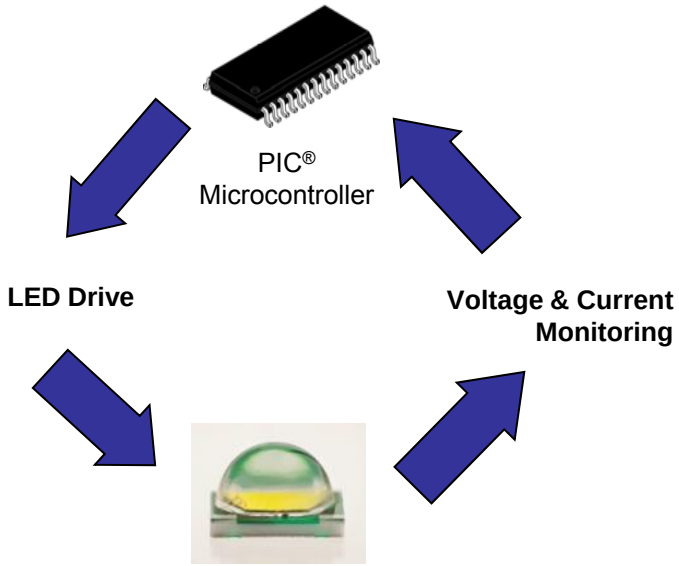
- Prevent over heat of LED and Luminaire
  - Remove conducted heat of LED
  - Active cooling solution (fans, etc.)
  - Passive cooling via power output reduction
- Safety Critical
  - Prevent catastrophic failure
- Maximum Luminaire Lifetime
  - Over temperature reduces LED life
  - Maintain optimal LED control



Predictive Failure

Predictive Failure & Maintenance

- Early Fault Detection
  - Monitor electrical degradation
  - Increased current consumption
- Safety Critical
  - Early detection
  - Reduce light to safe operation prior to replacement
- Reduced Maintenance
  - Remote notification

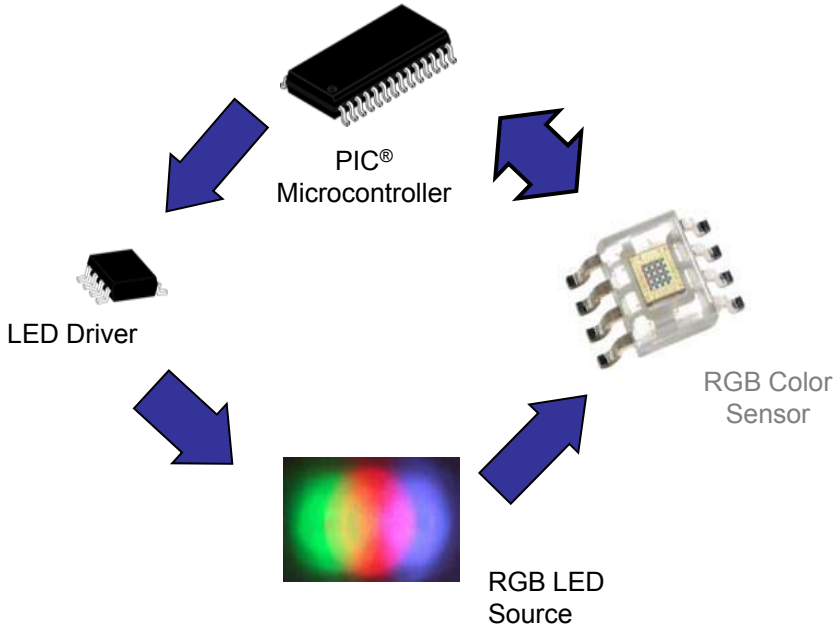


Color Control

Dynamic Color Control

- Maintain specific color or color temperature
  - Auto correct over lifetime degradation (aging)
  - Consistent light over large areas
- Requires precision dimming for R, G, B, W
  - High resolution PWM
  - High resolution analog output
- Color sensor calibration
  - Specific LEDs
  - Installation environment

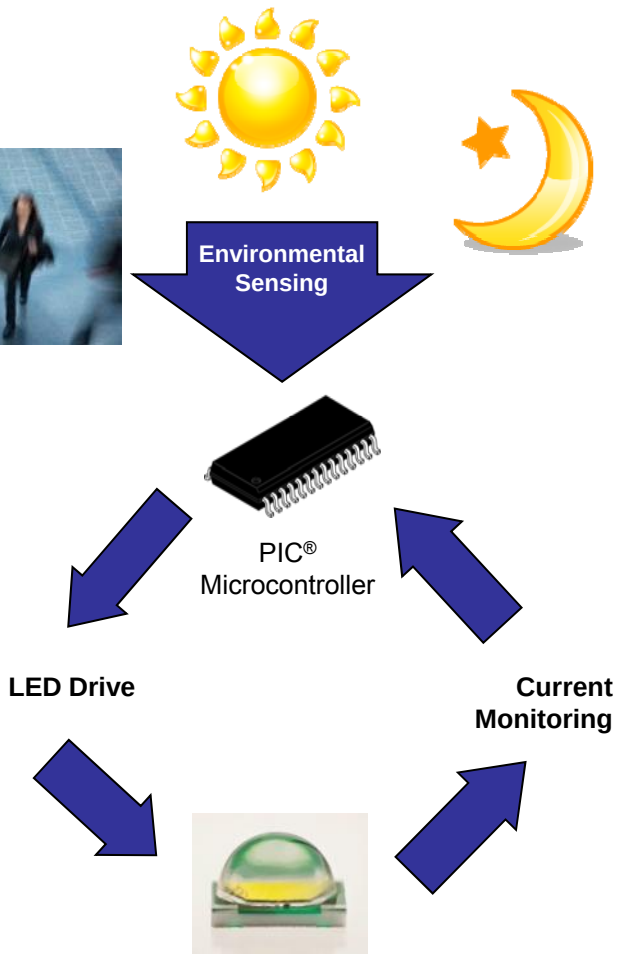
  OR
- LED Degradation Compensation
  - Monitoring Temperature & Age
  - Look-Up table based adjustments



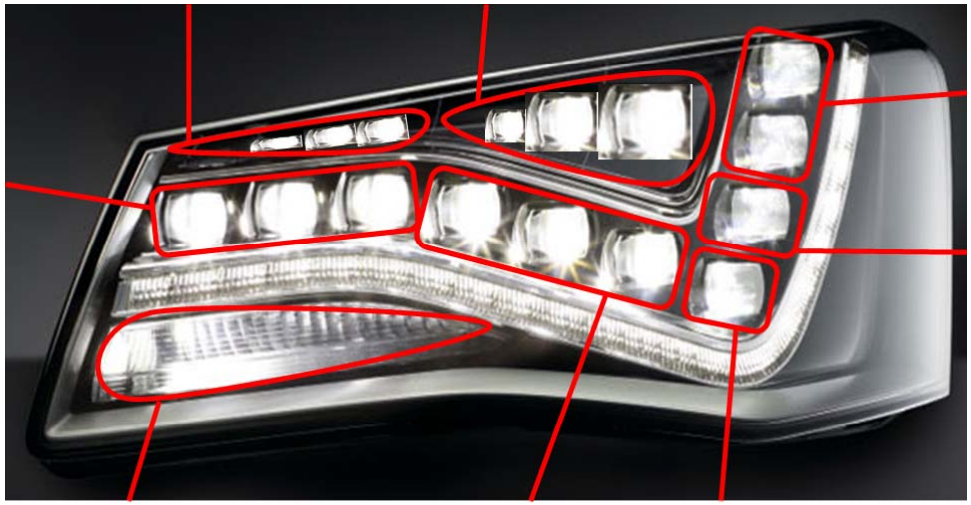
Environmental Sensing

Environmental Luminaire Control

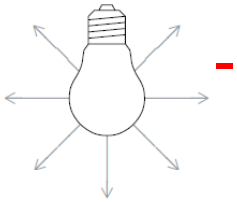
- Interaction with luminaire environment
  - Motion/occupancy sensing
  - Day & Night sensing
  - Any sensor type or Timers
- Reduce Power Consumption
  - Light only when needed
  - Daylight Harvesting
    - Automatic lumen control based on external lighting
- Maximum Luminaire Lifetime
  - Increased useable lifetime of Luminaire
  - Increased energy savings



LED Basics

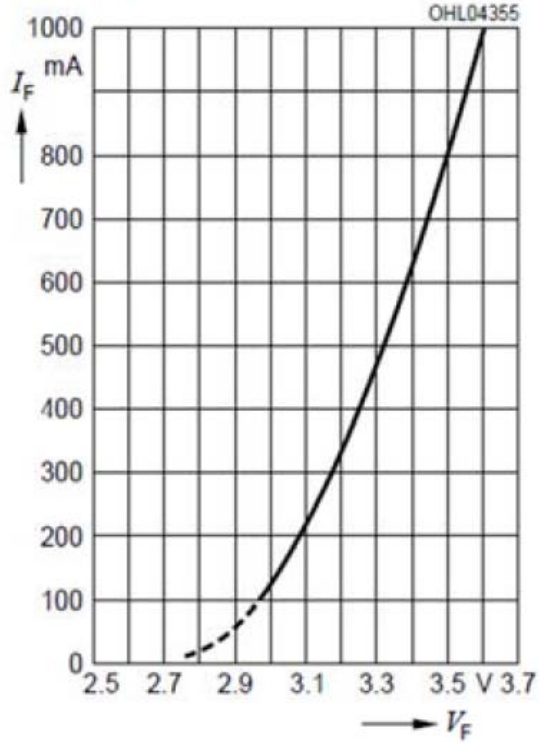


LED Basics



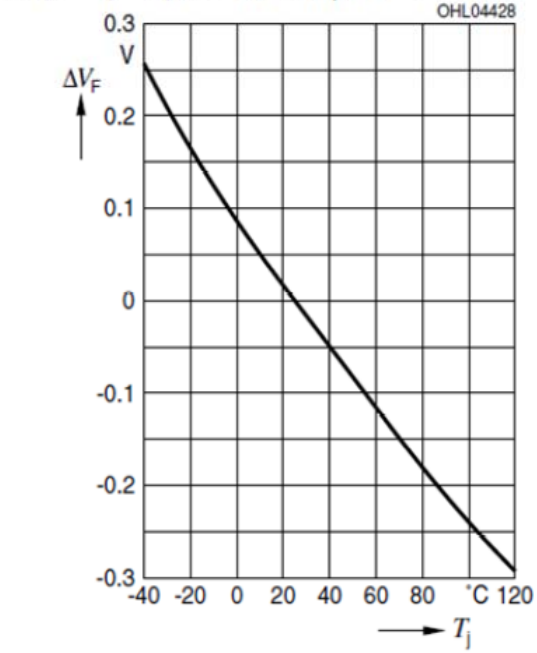
Forward Current[2] page 18

$I_F = f(V_F)$; T_S = 25 °C



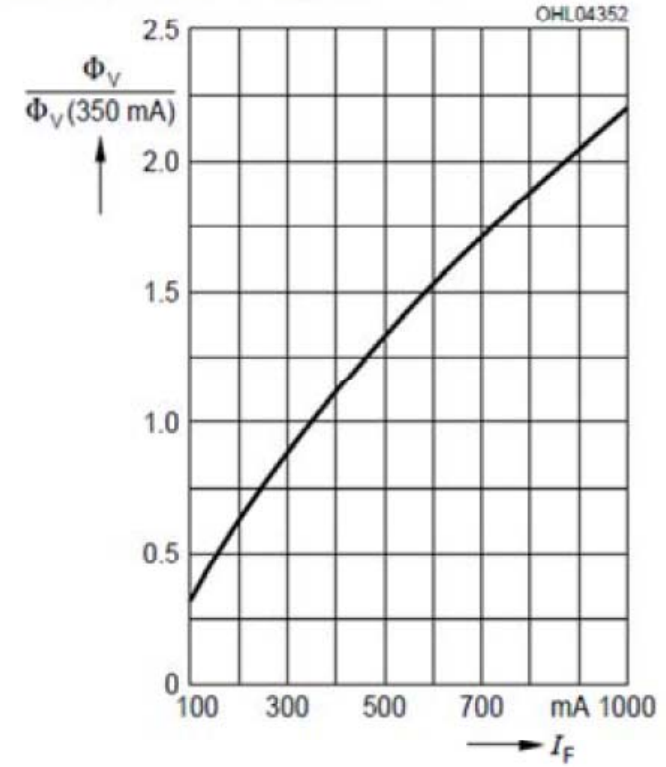
Relative Forward Voltage[2)4)] *page 17*

$\Delta V_F = V_F - V_F(25\ °C) = f(T_j)$; I_F = 350 mA



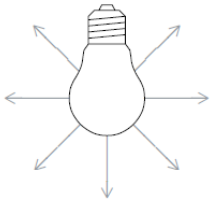
Relative Luminous Flux[2) 5)] page 18

$\Phi_V/\Phi_V(350\ mA) = f(I_F)$; T_S = 25 °C



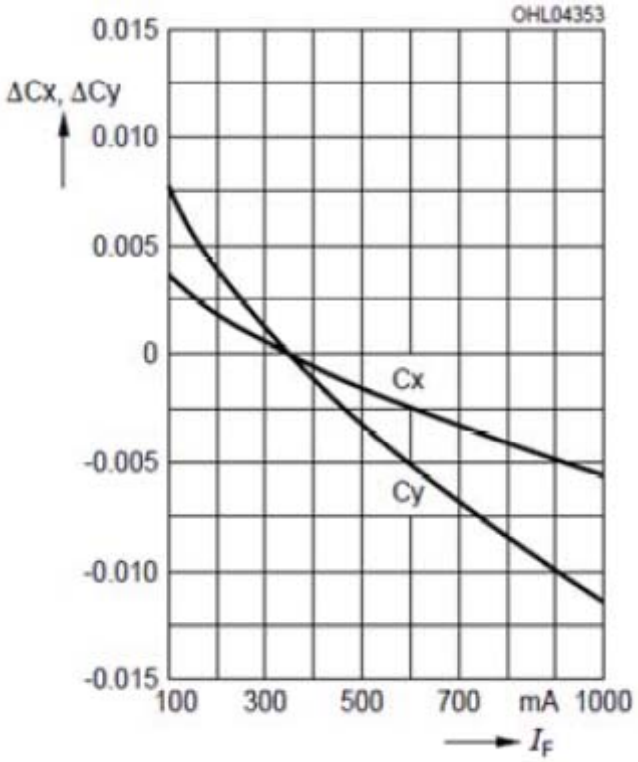
Luminious Flux (Lichtstrom) Lumen, lm, cd/sr

LED Basics



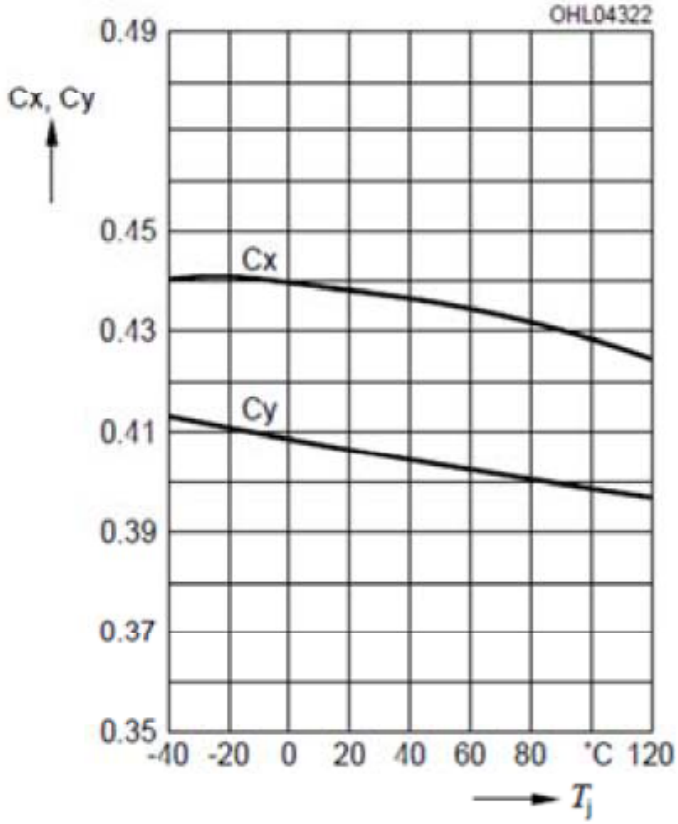
Chromaticity Coordinate Shift[2) Seite 18]

x, y = $f(I_F)$; T_S = 25 °C

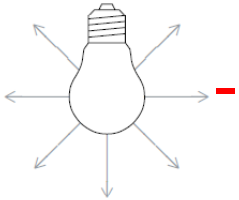


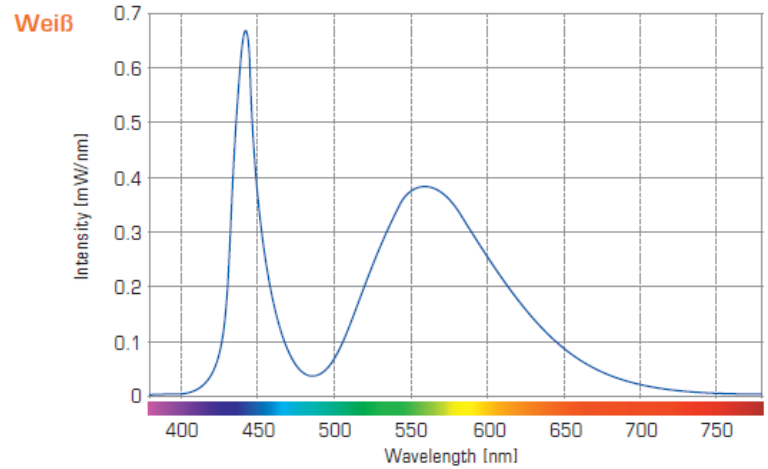
Chromaticity Coordinate Shift[2) page 20]

x, y = $f(T_j)$; I_F = 350 mA

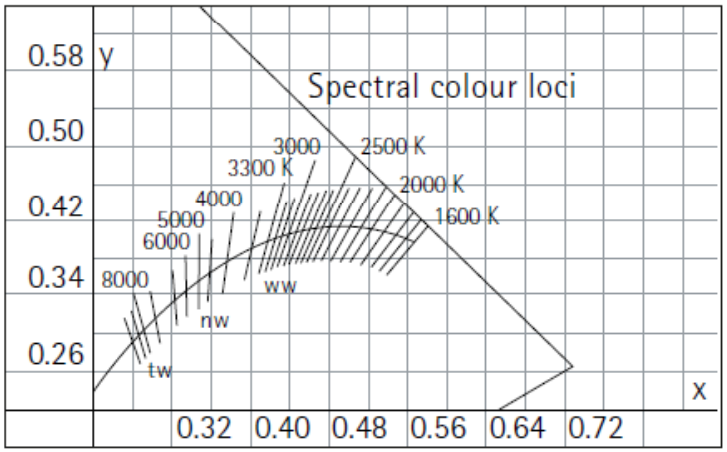


LED Basics

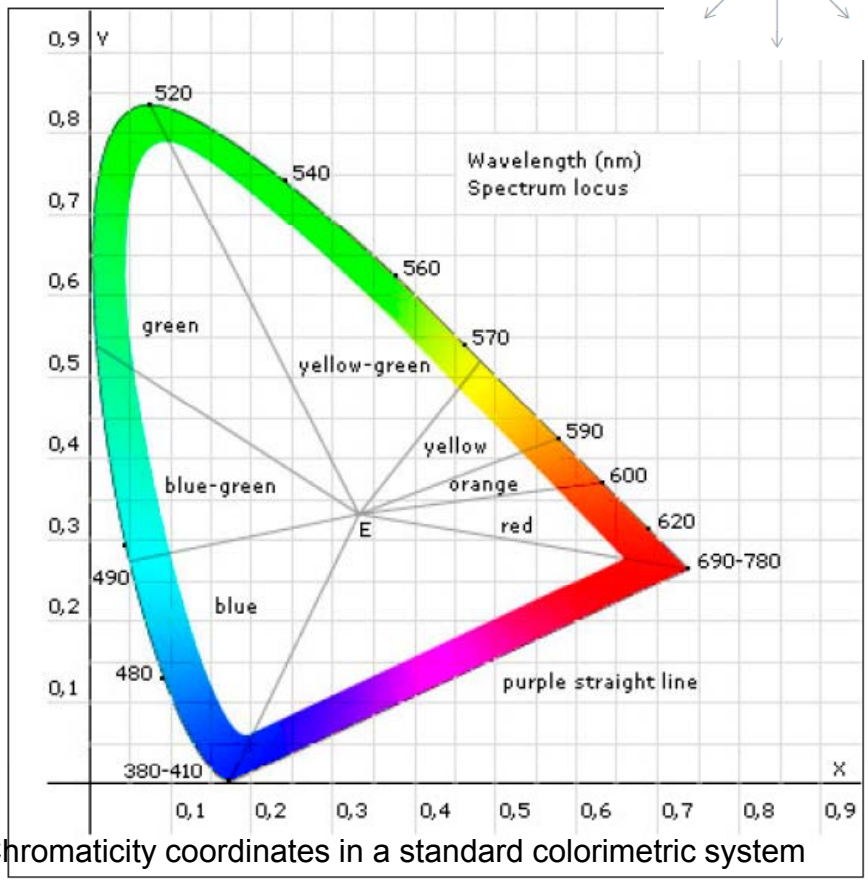




White LED spectrum



Color temperature

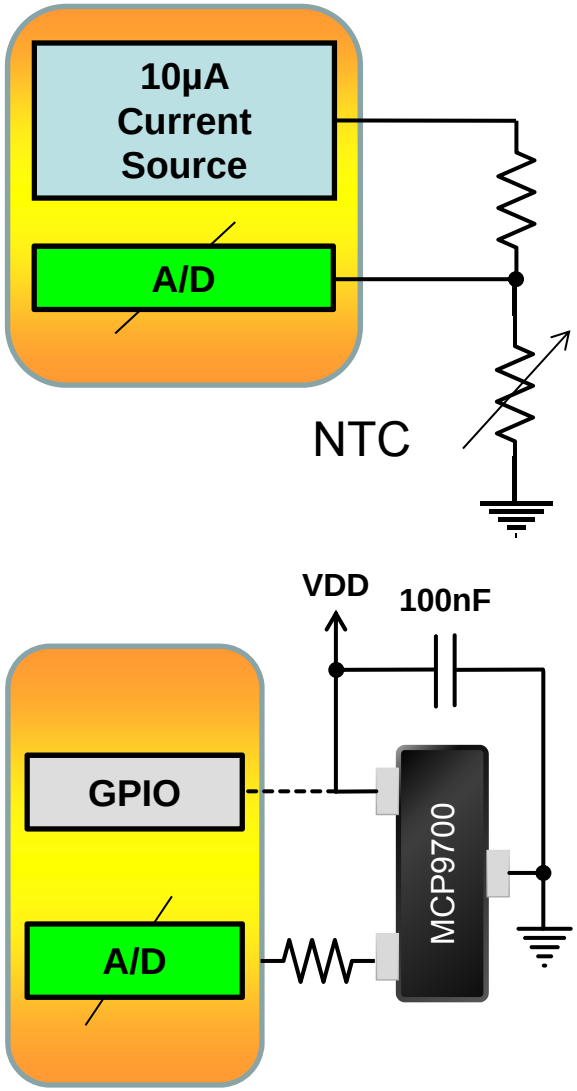


Chromaticity coordinates in a standard colorimetric system

http://www.biyee.net/color-science/cie-chromaticity-diagram

Adaptive Control

- **Temperature Compensation**
  - Commonly used sensor type is a semiconductor element with negative temperature coefficient (NTC)
    - Current source offers higher precision
    - Improved control of color temperature
    - Enhanced failure detection
    - „LED Disconnected“ detection
  - Fully compensated sensors
    - Have similar requirements
    - Offer high precision at high temperatures
    - Dedicated for on-board temperature sensing (LED driver board) for enhanced NTC compensation



Thank You

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